The structure and geochemistry of gold mineralisation in the Mt Todd goldfield, Pine Creek Inlier, Northern Territory

Appendices

by

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Appendix A: Maps

Figure 3.12a: Lithological interpretation - 1:10,000 scale map with stratigraphic column of the Burrell Creek Formation.

Figure 3.12b: Lithological interpretation (supplementary) - 1:10,000 scale map with stratigraphic column of the Burrell Creek Formation and the Tollis Formation.

Appendix B: Maps

Appendix C: Map

Figure 4.11: A structural interpretation of the Mt Todd goldfield - 1:15,000 scale map.

Appendix D: Maps

Figure 5.1: Geology of the Quigleys pits - 1:1000 scale.

Figure 5.2: Fact geology over a cleared area on Batman Hill - 1:50 scale.

Figure 5.3: Fact geology recorded on a sketch of the south-western face of the Quigleys

Appendix E:

List of thin sections (described).

SECTION NOS	DEPTH (M)	SECTION TYPE	MACRO DESCRIPTION	REF NOS.	DES
A001	0 00	TS	muddy sandstone with turbiditic affinity	A042	Y
A002	0 00	PS	gossaneous buck quartz breccia	A043	Y
A003a	0 00	DPTS	buck quartz, epithermal quartz.	A044	Y
A003b	0 00	DPTS	buck quartz, epithermal quartz.	A044	Y
A004	0 00	DPTS	quartz vein breccia	A045	Y
A005	0 00	TS	homfelsed shale and siltstone with X2 fold history	A046	Y
AB001	0 00	TS	weathered laminated shale, pre-S1 spotting; S1 veins, fabric, slickensildes, S2 veins	B147	Y
AN001	0 00	TS	quartz porphyry	B155	Y
AN002	0 00	TS	very coarse biotite-plagioclase-quartz-Kspar leucogranite	B156	Y
AN003a	0 00	TS	very coarse porphyritic biotite-andesine-quartz-Kspar leucogranite	B156	Y
AN003b	0 00	TS	very coarse porphyritic biotite-andesine-quartz-Kspar leucogranite	B156	Y
BD001a	52 10m	PTS	homfelsed siltstone; quartz-pyrrhotite vein; pyrite; chalcopyrite vein, sphalerite, chlorite	A178	Y
BD001b	99 3m	PTS	siltstone; quartz-pyrrhotite vein, calcite and chlorite vein	A179	Y
BD001c	138 6m	PTS	homfelsed muddy sandstone & silty shale, quartz-sulphide veins, quartz-cc vein, cal vein	A180	Y
BD001d	180 0m	PTS	siltstone, quartz-pyrrhotite vein, pyrite, chlorite & calcite vein	A181	Y
BD002a	41 88m	PTS	qt-py vein	A182	Y
BD002b	41 88m	PTS	quartz-pyrite vein	A182	Y
BD002d	86.80m	PTS	sandy siltstone, po-ccp-lo-py1-py2-marc-arsen-cal	A184	Y
BD003c	100 00m	PTS	py-,arc-ccp-gn-sph	A188	Y
BD004b	86 80m	PTS	quartz-pyrite vein	A190	Y
BD006a	147 25	PTS	qtz-po-ccp-Au-tal-bis vein, sandy siltstone	B006	Y
BD006b	101 3m	PTS	sandy siltstone, qtz-po-qtz-chl-ccp-py-sph-arsen-cal-py-chl-cal vein	B005	Y
BD006c	119-120m	PTS	PTS only	B009	Y
BD006g	189 80m	PTS	PTS only	B013	Y
BD006i	336 1m	PTS	quartz-pyrrhotite-pyrite vein	B008	Y
BD008a (1)	98-99m	PTS, DPTS	epithermal calc-sulphide assemblage	A167	Y
BD008a (2)	98-99m	PTS, DPTS	epithermal calc-sulphide assemblage	A167	Y
BD008a (3)	98-99m	PTS, DPTS	epithermal calc-sulphide assemblage	A167	Y
BD008c	90 90m	PTS	homfelsed muddy sandstone, qtz-po, qtz-chl-ccp, py, arsen, py-chl-cal/S2	B027	Y
BD013a	113 05	PTS	qtz-po vein, calcite vein	B033	Y
BD016c	151 45m	PTS	shale, qtz-po-ccp-arsen-Au-bis-Bi-tal, chl-cal-sph vein	B043	Y
BD018a	88 10m	PTS	PTS only	B048	Y
BD021b	117 50m	PTS	quartz-pyrrhotite-pyrite vein	B053	Y
BD023a	41 90m	PTS	gross py vein	B059	Y
BD027a	172 20m	PTS	quartz-pyrrhotite-pyrite vein	B062	Y
BD027e	333 2m	PTS	quartz-pyrrhotite vein in a sandy siltstone	B066	Y
BD056b	85 30m	PTS	pellett in homfelsed shale	B070	Y
BD056c	101 40m	PTS	pellett & sediment, homfelsed, S2, quartz-chlorite vein	B070	Y
BD056d	114 50m	PTS	homfelsed shale, quartz-chlorite vein, calcite-pyrite vein	B070	Y
BD056e	115 20m	PTS	homfelsed shale, quartz-chlorite vein, chlorite vein, quartz-calcite vein	B070	Y
BD057a	120 46m	PTS	homfelsed sandy shale, quartz-chlorite vein, quartz-chlorite-chalcopyrite, chlorite-calcite fill	B071	Y
BD060a	2 60m	PTS	chlorite aggregate	B072	Y
BD074a	60 00	PTS	homfelsed sandy shale	B079	Y
BD075a	67 95m	PTS	homfesed siltstone & muddy sandstone, quartz vein, chlorite-pyrite vein	B080	Y
BD079b	264.0m	PTS	gross py	B092	Y

THIN SECTION LIST

BD080q (1-3)	286 95	PTS	qtz-po-calc vein	B100	Y
BD081a (1 & 2)	141 65-141 71m	DPTS	Pyrrhotite-galena-sphalerite-calcite vein, arsenopyrite vein, muddy sandstone	A151	Y
BD087a (1)	267 78-297 94m	PTS	sandy siltstone, qtz-po-ccp-chl; calc-base metal, arsen, calc-base metal colloidal vein/S2	A169	Y
BD087a (2)	267 78-297 94m	DPTS	very fine sandstone; pyrrhotite vein, chalcopyrite-sphalerite-galena vein	A169	Y
BD090d (1)	222 13-222 21m	PTS	Quartz-pyrrhotite vein, chalcopyrite-chlorite-sphalerite-quartz vein	A159	Y
BD090d (2)	222 13-222 21m	DPTS	Quartz-pyrrhotite vein, chalcopyrite-chlorite-sphalerite-quartz vein	A159	Y
BS001	0.00	PB	gossaneous Au-bearing qtz breccia	A038	Y
BS002	0 00	TS	finely spotted, X2 deformed, X2 hornfelsed siltstone	A039	Y
BS003a	0 00	TS	weathered mineralised porphyritic quartz microsyenite	0	Y
BS003c	0 00	PTS	mineralised porphyritic quartz microsyenite	A040	Y
C001 a & b	0 00	TS (X2)	sericitised, hornfelsed, X2 deformed leucogranite	A010	Y
C002	0 00	TS	microcline-plagioclase-quartz-biotite leucogranite	A011	Y
C003	0 00	TS	deformed porphyritic K-feldspar leucogranite	A012	Y
C004	0 00	TS	hornfelsed sandy siltstone	A013	Y
C007 (1)	0 00	TS	X2 hornfelsed, X2 deformed siltstone and fine sandstone with pellet	A016	Y
C007 (2)	0 00	TS	X2 hornfelsed, X2 deformed siltstone and fine sandstone with pellet	A016	Y
C007 (3)	0 00	TS	X2 hornfelsed, X2 deformed siltstone and fine sandstone with pellet	A016	Y
C008b (2)	0 00	DPTS	veined and greisenated leucogranite	A018	Y
C009a	0 00	PTS	buck quartz vein, chlorite-pyrite vein	A019	Y
C009b	0 00	PTS	fluorite-adularia-muscovite greisenated hornfelsed leucogranite	A019	Y
C011	0 00	TS	chloritised dolerite	A026	Y
C015	0 00	TS	hornfelsed coarse siltstone + greisenated leucogranite	A051	Y
CHL001	0 00	PTS	sheared sandy siltstone; X2 fabric; fabric shearing crack-seal veins	B151	Y
CHL002	0 00	PTS	sandy lithic siltstone, crack-seal quartz vein; microfaulting and pyritisation	B151	Y
CHL003	0 00	PTS	hornfelsed laminated fine siltstone, S1 fabric, crack-seal vein, microfaulting	B152	Y
DC001	0 00	DPTS	epithermal quartz	A033	Y
G001	0.00	PTS	buck quartz, hematite, epithermal quartz, hematite, epithermal quartz, goethitised	A003	Y
GN002	0 00	TS	x2 hornfelsed laminated shale with x2 fold history	A020	Y
GN003	0 00	PTS	hornfelsed, X 2 deformed, laminated shale	A035	Y
GN004	0 00	PTS	weathered laminated shale, quartz vein	A036	Y
J001	0 00	PTS	X 2 deformed, weathered very fine sandstone	A029	Y
J002	0 00	PTS	epithermal quartz	A066	Y
JG002 (1)	0 00	TS	prismatic quartz replacement of epithermal calcite	A030	Y
JG002 (2)	0 00	PTS	prismatic quartz replacement of epithermal calcite	A030	Y
JG003	0 00	TS	tuffaceous siltstone	A031	Y
LSS001	0 00	PTS	quartz syenite - Lewin Springs Syenite	A049	Y
MT001b	0 00	PS	wolframite-quartz vein	A055	Y
MT013	0 00	PTS	crosscutting veins	B148	Y
MTW001	0 00	TS	porous nodular ferruginised clayey sand	A054	Y
PGD007d	96 12-96 18m	DPTS	quartz vein, galena vein in brecciated sediment	A086	Y
PGD011-4A	60 69-60 78m	DPTS	quartz vein, galena vein in brecciated sediment	A166	Y
Q001	0 00	TS	a heavily weathered, X2 deformed, shale	A021	Y
QD001l	79 20m	PTS	qtz-py-ars vein	B126	Y
QD002e (1)	144 76-144 89m	PTS	calcite-base metal vein in brecciated poorly sorted sandstone	A122	Y
QD002e (2)	144 76-144 89m	DPTS	calcite-base metal vein in brecciated poorly sorted sandstone	A122	Y
QD002h	231 52-231 6m	PTS	po in breccia	A125	Y
RD001a	55 15m	PTS	arsen-py vein	A098	Y

T001	0 00	TS	hornfelsed, felsic tuffaceous sandy siltstone	A007	Y
T002	0 00	TS	X2 deformed, silty lithic sandstone	A009	Y
TD002a	210 35-210 4	PS	pyrite-arsenopyrite-quartz vein	A047	Y
TD002b	220 47-220 51	DPTS	epithermal quartz	0	Y
TD002f	221,09-221 135	PTS	po vein; qtz vein	A135	Y
VV001	0 00	TS	X2 deformed, granular meta-gravel	A024	Y
WB001	0 00	TS	X2 hornfelsed, K-metasomatised siltstone & sandy siltstone, qtz-chl-K-spar-rutile vein, qtz vein	B149	Y
WB002	0 00	TS	X2 hornfelsed siltstone, D1 slickenslides; crack-seal veining	B149	Y
WB003	0,00	TS	X2 hornfelsed finr grained lithic sandy siltstone, qtz-chl-musc-opaques vein; goethite vein	B150	Y
Y001	0 00	TS	X2 hornfelsed pyrite-shale with X1 fracture/folc history	A052	Y
YEN001	0 00	TS	greisenated, weakly deformed, coarse grained, biotite-andesine-microcline-quartz leucogranite	0	Y
YEN020A	0 00	TS	greisenated, weakly deformed, coarse grained, biotite-quartz leucogranite	0	Y

Appendix F:

Thin section descriptions.

reprint entire

A001
Tollis Formation - Accident
Ref Nos: A42
TS

Macroscopic:- greywacke with siltstone blebs.

Microscopic:-
clasts:- (60%) Maximum clast size is 400 μm
quartz:- (38%) anhedral, angular to subrounded; some clasts contain numerous fluid inclusions suggesting a quartz vein origin; some clasts contain apatite crystals and rutile needles suggesting an igneous origin; some clasts are strained suggesting a metamorphic origin.
plagioclase:- (4%) anhedral.
quartzites:- (6%) angular clasts; polygonal texture and concavo-convex types.
chert:- (2%) angular clasts.
K-spar:- (10%) heavily sericitised and chloritised.
zircons:- (tr) euhedral in nature and usually within feldspars suggesting an igneous origin.
tourmaline:- (tr) anhedral to subhedral.
matrix:- (40%)
chlorite:- (14%) fine plates (~10 μm); occurs as a cementing matrix to clasts and commonly occurs as an alteration of feldspars. Seem to define a weak cleavage.
sericite:- (14%) fine plates (~10 μm); occurs as a cementing matrix to clasts and commonly occurs as an alteration of feldspars. Seem to define a weak cleavage.
opaques:- (6%) occur throughout as tiny patches (<10 μm) or clots (100 μm). The clots look like aggregates of the tiny patches and are probably hematite.
Fe-oxides:- (6%) occur throughout as tiny patches (<10 μm). Seem to define a weak cleavage.

Interpretation:- A poorly sorted, grain supported, medium sandstone with a chloritised, sericitised and hematised matrix. It was probably a muddy sandstone originally. A weak fabric is defined by the poor alignment of chlorite, sericite and Fe-oxides. Bedding is apparent from the alignment of siltstone blebs (up to 2 cm in size) as seen in hand specimen, but is not apparent microscopically. Elongation of the siltstone blebs suggests some deformation. The angularity and poorly sorted nature of the clasts would suggest rapid deposition close to the sediment provenance. The existence of medium sized clasts, siltstone blebs, and the fine matrix, support rapid deposition of the sediment, possibly as a turbidite. A mixed igneous - metamorphic provenance is indicated by the presence of feldspars and igneous quartz together with cherts and quartzites.

1. Sedimentation.
2. Deformation?

Name:- muddy sandstone (with turbiditic affinity).

A002
Tollis Formation - Accident
Ref Nos: A43
PB

Macroscopic:- gossaneous buck quartz breccia.

Microscopic:-
pyrrhotite:- (tr) anhedral crystals to 10 μm in size; smooth curved contact margins with chalcopyrite.
chalcopyrite:- (tr) anhedral crystals to 20 μm.
hematite:- (15%) fine grained coating in rims around and along fractures; type of reniform growth; vuggy in morphology and has acted as fill.
goethite:- (25%) after hematite.
quartz:- (60%) major gangue mineral, contains numerous fluid inclusions (=> buck quartz).

Interpretation:- Copper minerals probably represent the original vein sulphide constituent and have been preserved as tiny relic inclusions in quartz. Chalcopyrite and pyrrhotite contact margins are smooth and curved indicating either co-precipitation or equilibrium. Hematite is not crystalline in its form, and is probably low temperature in origin, perhaps even epithermal. Goethite is a late alteration product of hematite.

1. Buck quartz.
2. Fracturing.
3. Po-ccp.
4. Fracturing.
5. Hematite/goethite

Name:- gossaneous buck quartz breccia.

A003a & b
Tollis Formation - Accident
Ref Nos: A44
DPTS

Macroscopic:- buck quartz/epithermal quartz.

Microscopic:- sample is all quartz - generally the section consists of a massive milky white anhedral quartz containing hundreds of tiny (2-3 μm) fluid inclusions. The sample is crisscrossed by numerous parallel fractures and it is difficult to relate all of these to crack-seal events. Certainly, individual quartz crystals exceed 1 cm in length the majority of fluid inclusion trails are perpendicular to the crystal length. This may indicate that the quartz has developed during crack-seal veining.
The sample has been considerably fractured after crack-seal veining. Several zones contain a dense array of fluid inclusions. Most of these zones relate to fracturing, i.e., the zones are the sites of repeated fracturing and sealing events. Other zonation may be a feature of crystal growth.
In part, the section is veined by epithermal quartz, i.e., dog tooth quartz has developed. This indicates that open space fill has been a part of vein history. Epithermal quartz crystals are zoned, as defined by fluid inclusions (the fluid inclusions are usable for analyses). Epithermal veins are developed parallel to crack-seal fluid inclusion trails.
Fe-oxides occasionally stain the surface of crystal terminations, and may also be found along fractures.

Interpretation:-
1. Buck quartz.
2. Fracturing.
3. Dog tooth quartz.
4. Hematite/goethite.

Name:- Buck quartz/epithermal quartz.

A004
Tollis Formation - Accident
Ref Nos: A45
DPTS

Macroscopic:- quartz vein breccia.

Microscopic:- brecciated sediment which has been filled in by quartz. The quartz fill is clearly open space fill with vugs into which crystals terminate. Crystals are zoned, the zoning defined by alternating bands of fluid inclusion rich quartz and fluid inclusion poor quartz. The sediment is chloritised while the whole of the sample has been goethitised, i.e., Fe-oxide staining can be found associated with the sediment and within fractures crossing the quartz.

Interpretation:-
1. Sedimentation.
2. Fracturing.
3. Dog tooth quartz.
4. Goethite.

Name:- epithermal quartz.

A005
Tollis Formation - Accident
Ref Nos: A46
TS

Macroscopic:- tightly folded greywacke

Microscopic:- Poorly sorted quartz-sericite unit is juxtaposed against a hornfelsed shale unit. The quartz-sericite unit was probably a poorly sorted, poorly rounded, medium silt. The shale unit is composed almost entirely of sericite-chlorite. The bed contains cordierite spots now totally altered to sericite, chlorite and Fe-oxide.

Interpretation:- Circular (spherical) cordierite spots would originally have developed in a manner independent of any previous fabric orientation. The spots contain a fabric (call S1) and this fabric has been folded (call S2). Clearly, the cordierite spots precede S1 and S2, given that the spots contain the S1 fabric. The spots are relatively undeformed in the hinge of the S2 fold, but are elongated or stretched in the hinge of the S2 fold. The overall appearance is virtually equivalent to that as shown by Ramsay and Huber (1987, The techniques of modern structural geology, Vol 2, folds and fractures, p 447, Figure 213) in a diagram which demonstrates the effect of deforming a pack of cards with circles on the side to produce a flexural slip fold in which there has been no initial strain or slight oblique flexural strain. It is possible that the D2 fold formed in a similar manner.
Cordierite spots in the hinge of the S2 fold are $\approx$ 0.2 mm (200 μm) in size, similar to spots seen elsewhere.
The S1 fabric, as defined by sericite and chlorite, appears to be parallel to sub-parallel (70°-80°) to bedding.
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Deformation D2 - S2 fold.

Implications:- The slide supports two deforming events in the Mount Todd region with one hornfelsing event occurring before the first deformation. The geo-history of this slide can be interpreted as sediment deposition, hornfelsing with the development of cordierite spots, retrogression, D1, D2.

Name:- hornfelsed shale and siltstone with X2 fold history.

AB001
Alpha Bravo
Ref Nos:- B147
TS

Macroscopic:- slickenslides (orientated thin section). The section is cut parallel to the slickenslide fibres which are orientated 43° ---> 280°.

Microscopic:-
wallrock:- a laminated shale unit. Clasts are composed of chlorite, sericite and quartz (< 10 μm in size). Goethite plates are scattered throughout the shale but are also clustered around ovoid patches of chlorite and sericite, which are psuedomorphs after cordierite. The chlorite and sericite define an S1 fabric (which dips ~ 50° W). The ovoid patches are elongate parallel to the S1 cleavage.
slickenslides:- are bedding parallel but are poorly developed. In hand specimen the sense of movement is reverse, i.e., west block east and up, and in thin section this is confirmed by stepping of the surface to the east. East-west transport is consistent with flexural slip during D1.
veins:- vein 1:- numerous discontinuous quartz filled en èchelon micro-veins which measure 5 μm X 125 μm. They are sub parallel to S1 (~ 15° difference) and crosscut the fabric, both in the cordierite psuedomorphs and chlorite sericite fabric. They thus postdate hornfelsing and S1. With respect to orientation, the short axis of the veins must approximate $\sigma3$, i.e., the extension direction, and this dips ~ 40 ° E. This approximates $\sigma3_{D2}$.
vein 2:- chlorite veins:- strongly weathered fine(< 1 μm) chlorites. They are cut by vein 1 and vein 3 and thus must be early. The veins dip west and crosscut the slickenslides, S1 fabric, and the cordierite spots
vein 3:- they dip west and are a discontinuous set of quartz sericite veins which terminate at vein 1 at both ends. The veins are syn-vein 1 and crosscut slickenslides, S1 fabric and the cordierite spots.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric, spot elongation, slickenslides, ?chlorite veins.
4. Deformation - S2 fabric as quartz microveins and quartz-sericite veins.
5. Goethitisation.

Name:- weathered laminated shale/pre-S1 spotting/S1 veins, fabric,slickenslides/S2 veins.

AN001
Mafic plug/dyke in the Tennysons leucogranite - Anomaly 1 traverse
Ref Nos:- B155
TS

Macroscopic:- Dark grey quartz porphyry

Microscopic:- Described by the BMR as the Plum Tree Creek Volcanics.
phenocrysts of quartz:- euhedral to subhedral, uniaxial (+), margin regrowth is evident from the incorporation of groundmass crystals, 1.8 mm in size, define a slight poiklioblastic texture, chadacrysts (400 μm in size) of plagioclase, biotite and accessory hornblende indicate that the phenocrysts had a mafic origin.
groundmass:-
- quartz:- (65%) 100 μm in size, anhedral and equant.
- muscovite:- (20%) 600 μm in size, subhedral and slightly chloritised.
- biotite:- (6%) 600 μm in size, subhedral and slightly chloritised, associated with accessory zircons (<5 μm in size).
- clinozoisite:- (3%) 100 μm long, scattered throughout the section.
- calcite:- (3%) interstitial, not possible to determine if primary or secondary in nature.
- opaques:- (3%) altered to goethite.
- zircons:- accessory

Interpretation:- Has been described as the PTV by the BMR. Clinozoisite, goethite, calcite and the chloritised nature of the muscovite and biotite indicate post-emplacement alteration, making description difficult.

1. Emplacement of the quartz porphyry.
2. Chloritisation.
3. Goethitisation.

Name:- Quartz porphyry.

AN002
Sheared Tennysons leucogranite - Anomaly 1 traverse
Ref Nos:- B156
TS

Macroscopic:- Coarse grained quartz, plagioclase, K-spar, biotite granite.

Microscopic:-
biotite:- (10%) 3 mm in size, euhedral crystals, slightly chloritised.
zircon:- (2%) 50 μm in size, euhedral, strong association with uranium haloes in the biotite.
K-spar:- (30%) 3-4 mm in size, microperthitic texture common, i.e., S-spar exsolution from K-spar, exhibits some glomeroporphyritic texture.
S-spar:- (15%) 1 mm in size, as rare single crystals, largely associated with microperthitic texture in K-spar.
quartz:- (30%) 3 mm in size, euhedral to subhedral.
muscovite:- (2%) <1 mm in size and scattered throughout, also in the form of sericite associated with deuteric alteration of feldspars.
opaques:- accessory

Interpretation:- very coarse granite which is probably phenocrystic given the size of the K-spar. Since FeMg minerals are < 30%, the granite is leucocratic.

1. Emplacement.
2. Deuteric and sericitic alteration.

Name:- Quartz-S-spar-biotite-K-spar leucogranite.

AN003a & b
Tennysons leucogranite - Anomaly 1 traverse.
Ref Nos:- B156
TS

Macroscopic:- Quartz phenocrystic, biotite-quartz-plagioclase-K-spar leucogranite

Microscopic:-
Phenocrysts (15%):-
- quartz:- (8%), subhedral monocrystalline grains ~ 5 mm in size, wavy to undulose extinction features.
- biotite:- (3%) anhedral ~ 1 cm in size, sub-poiklioblastic in texture, chadacrysts of quartz, K-spar, plagioclase.
- K-spar :- (4%) subhedral laths ~ 1.5 cm long, display microperthitic texture with exsolution of plagioclase from K-spar.

Groundmass (85%):-
- biotite:- (5%) subhedral (400 μm in size) greenish brown and brown (=> low Fe^{3+} and Ti and high Fe^{2+}), associated with zircons which cause Ur haloes in biotite crystals.
- muscovite:- (2%) subhedral (200 μm in size) pale green colour => Fuchsite from deuteric alteration of biotite, also found at the margins of biotite.
- sericite:- (2%) subhedral (<5 μm in size),replaces plagioclase and K-spar in part.
- quartz:- (25%) subhedral to euhedral, ~ 1.6 mm in size, wavy undulose extinction.
- K-spar:- (35%), subhedral, simply twinned crystals, ~ 1.6 mm in size showing exsolution of plagioclase (microperthitic texture).
- S-spar:- (15%), 3.2 mm in size,, Andesine (Ab38-An), some sericite alteration.
- zircons :- (tr) associated with biotite, 120 μm in size.
- Fe-oxides:- (1%), throughout the section and associated with spars and sericite alteration of spars.

Interpretation:-	K-spar	39%	(49%)	
	S-spar	15%	(18%)	therefore a granite.
	qtz	25%	(31%)	

FeMg mineral <30% = leucocratic
Major minerals indicate porphyritic and very coarse.

1. Emplacement.
2. Deuteric and sericitic alteration.

Name:- Very coarse porphyritic biotite-andesine-quartz-K-spar leucogranite which has suffered some deuteric alteration.

BD001a
Batman Hill, DDH BD001 - 52.10 m.
Ref Nos: A178
PTS

Macroscopic:- Pyrite-quartz vein

Microscopic:-
chalcopyrite:- postdates pyrite, i.e., in fractures in pyrite, some alteration to covellite.
sphalerite:- rims chalcopyrite and have high Fe content to the core of grains.
quartz:- anhedral buck type quartz with numerous (>1 μm) fluid inclusions. Granoblastic quartz is the result of subsequent stress imposed on the quartz. Euhedral quartz which lies adjacent to pyrite and which is devoid of any fluid inclusions, probably postdates the buck quartz.
pyrite:- as a spongy psuedomorph after pyrrhotite.

A sample of chloritised siltstone that has been fractured and veined. The granoblastic texture is most dominantly developed at the sites of vein offset. Here there is offset parallel to stress features in the quartz together with the development of quartz sub-grains and margin serrations. Clearly this is not a temperature feature. Offset is bedding parallel and must have caused the development of open space network since zones of offset contain spherulitic chl + po + sph. Offset must therefore predate these. Some granoblastic grains are developed along the vein but are related to bending of the vein (again stress) and the presence of fluid inclusions would suggest that granoblastic quartz has not resulted from a re-equilibration with temperature. Furthermore, no true granoblastic texture is developed. Grains are small and not really polygonal in shape. In fact, some are jagged and show concavo-convex shapes rather than polygons, as associated with temperature re-equilibration. Furthermore, crack-seal textures seem more related to healed fractures. Chlorite veins are developed on the the vein wall. Spots (after cordierite) within the wall rock are altered to chlorite (cordierite -------> chlorite) and sericite is common throughout. Po + qtz are in equilibrium.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Quartz + pyrrhotite + chalcopyrite.
8. Po ---> py + marcasite
9. Fracturing.
10. Rims of sphalerite
11. Alteration/reaction of sphalerite to low Fe-sphalerite.
12. Fracturing.
13. Chlorite vein.
14. Fracturing - granoblastic re-equilibration textures, S2.

Mineralisation was accompanied by chlorite/sericite alteration and reaction of cordierite ---> chlorite in the wall rock. Wallrock is partially mineralized

Name:- hornfelsed siltstone, quartz-pyrrhotite vein, pyrite, chalcopyrite vein, sphalerite, chlorite.

BD001b
Batman Hill, DDH BD001b - 99.3 m.
Ref Nos:- A179
PTS

Macroscopic:- quartz+ pyrite + pyrrhotite + arsenopyrite + chalcopyrite vein in a siltstone.

Microscopic:-
Wallrock:- predominantly a siltstone greywacke. The presence of sericite and chlorite indicate a general alteration. Clusters of framboidal pyrite are scattered throughout. Two fabrics are defined by sericite and chlorite. One which is parallel to the vein wall, while the other is sub-perpendicular to the vein wall. Sericite laths of the second (S2) cut the first (S1). The wallrock and main vein are cut by a chlorite vein and a calcite vein. The calcite vein crosscuts the S2 fabric and the chlorite vein and thus is late.

Vein:- Quartz:- is elongate with long axis sub-parallel to the vein wall. It has the appearance of ribbons sub-parallel to the vein wall. Fluid inclusions are commonly perpendicular to this elongation and suggest a crack-seal growth of quartz. The quartz is stressed and the edges of the crystal are serrate. Subgrain development is more consistent with break up due to stress rather that to re-equilibrium with increasing temperature.

Fracturing has seen the precipitation of opaques in equilibrium with euhedral quartz. The quartz is clear and does not contain fluid inclusions.

Fracturing and calcite and chlorite veins follow closely around quartz-pyrrhotite boundaries. Granoblastic texture in the quartz implies re-equilibration and high stress. The timing of the texture is not clear.

Pyrrhotite:- anhedral masses which are being consumed by marcasite. The po forms smooth margins with ccp suggesting equilibrium.

Marcasite:- spongy anhedra consuming a sea of chalcopyrite. It is supergene.

Chalcopyrite:- anhedral masses. Smooth margins within po and may be in equilibrium.

Interpretation:-

1. Sedimentation.
2. Deformation with retrogression - S1 fabric.
3. Fracturing.
4. Crack-seal quartz.
5. Fracturing.
6. Quartz + pyrrhotite + chalcopyrite.
7. Fracturing
8. Chlorite vein.
9. S2 fabric.
10. Fracturing.
11. Calcite + pyrite vein
12. Marcasite (supergene).
13. Hematisation.

Name:- siltstone; quartz-pyrrhotite vein; calcite and chlorite veins.

BD001c

Batman Hill, DDH BD001 - 138.6 m.
Ref Nos:- A180
PTS

Macroscopic:- quartz + pyrite + arsenopyrite vein in bedded greywacke (sandstone and siltstone beds)

Microscopic:-

wallrock :- muddy sandstone/silty shale which contains opaques (5%), quartz (65%), chlorite/sericite (30%). There are cordierite psuedomorphs spots of sericite and chlorite: the sericite and chlorite define 2 fabrics which crosscuts the spots: one fabric is sub parallel and strong and the other is sub-perpendicular and weak. The former crosscuts the main vein and sulphides and thus must postdate those veins (call S2). Sphalerite, chalcopyrite and marcasite are disseminated throughout the wallrock.

sulphides:- chalcopyrite:- anhedral masses to 50 μm, consumed by pyrite.

pyrite:- anhedral masses throughout. Smooth curved, embayed margins with chalcopyrite and pyrrhotite. Pyrite consists of two phases, i.e., massive pyrite (at 250 μm) surrounded by spongy pyrite. Massive pyrite consumes pyrrhotite as determined from embayed inclusions of pyrrhotite in pyrite.

loellingite:- defined by its distinctive pleochroism and pale blue to khaki green to dark steel grey anisotropy, it occurs as anhedral masses and subgrains (to 5 μm), contacting pyrite and chalcopyrite, and forming irregular masses within arsenopyrite, marcasite and pyrite. It consumes chalcopyrite and pyrrhotite.

arsenopyrite:- large laths that tend to form a sea around everything else. Contacts marcasite, pyrite and chalcopyrite with smooth embayed or straight subhedral margins. Looks late, i.e., has grown after everything else as fill. Arsenopyrite commonly forms euhedral rims around loellingite.

marcasite:- defined by its distinctive pleochroism, it forms anhedral masses in spongy pyrite and is consuming in nature. Although anhedral, it is crystalline and not supergene in nature. It is overgrown by arsenopyrite, and consumes chalcopyrite.

There is evidence of a fabric transgressing the sulphides, as defined by the preferred orientation of marcasite and arsenopyrite laths, and in gangue.

A small quartz-pyrite vein cuts through the wallrock and part way through the main vein. It indicates that fracturing caused offset of the main vein prior to the precipitation of pyrite.

A small chalcopyrite-quartz-chlorite-calcite vein truncates S2 sericite in the wallrock. Furthermore the chlorites in the vein do not lie parallel the wallrock platey minerals. Rather they are random in orientation and syntaxial to the wallrock sericite. Also the vein crosscuts the main vein weakly: euhedral quartz or euhedral edges to the quartz (and some calcite rhombs) define were the fracture would have been. Thus this vein postdates the main vein, sulphides and S2 fabric.

<u>Interpretation</u>:-

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Quartz + pyrrhotite + chalcopyrite.
6. Loellingite.
7. Fracturing.
8. Pyrite 1 - solid anhedral pyrite consumes pyrrhotite and chalcopyrite. Pyrite 1 + quartz forms veins through the wallrock.
9. Fracturing.
10. Pyrite 2.
11. Marcasite (crystalline).
12. Arsenopyrite consumes pyrite 1 & 2.
13. S2.
14. Chalcopyrite-quartz-chlorite-calcite vein.

<u>Name</u>:- hornfelsed muddy sandstone & silty shale; quartz-pyrrhotite veins; quartz-chalcopyrite vein; calcite vein.

BD001d
Batman Hill, DDH BD001 - 180.8 m.
Ref Nos:- A181
PTS - Section is damaged.

Macroscopic:- quartz + pyrrhotite + pyrite vein in siltstone. Dominant set offset by bedding parallel shear. Au in arsenopyrite. Pyrrhotite, pyrite, marcasite, arsenopyrite and calcite.

Microscopic:-
wallrock:- Chloritised greywacke composed of quartz, chlorite, sericite and opaques. Quartz occurs as grains which have a weak fabric. Sericite and chlorite are part of the wallrock alteration system and defines two fabrics. The presence of some biotite may suggest that chlorite is an alteration feature of the biotite such that some opaques observed are Ti relics. Other opaques are framboidal pyrite patches.
Veins:- qtz-sulphide vein with offset. Quartz is syntaxial and anataxial. Crack-seal textures are evident. Where there is vein offset, granoblastic texture, or subgrain quartz and chlorite are developed.

Interpretation:-
1. Sedimentation.
2. Deformation & weak fabric (*?)
3. Fracturing.
4. Crack-seal quartz.
5. Fracturing.
6. Quartz + pyrrhotite.

Name:- siltstone; quartz-pyrrhotite vein; pyrite; chlorite & calcite vein.

BD002d
Batman Hill, DDH BD002, 86.80m.
Ref Nos:- A184
PTS

Macroscopic:- quartz-sulphide vein in sandstone greywacke.

Microscopic:-
wallrock:- composed of angular, matrix supported, quartz clasts (100 μm in size) in a matrix of quartz, chlorite, sericite and accessory zircons. Three fabrics are evident from the alignment of platey minerals:-
1. weak and sub-parallel to the vein wall and crosscutting with respect to the other two fabrics (S3).
2. moderate and 60° to the vein wall. This fabric is parallel to fine stress fractures in the vein and clearly crosscuts pyrite and arsenopyrite (S2).
3. moderate and 120° to the vein wall. Is not crosscutting with respect to the vein and the other two fabrics (S1).
Psuedomorphs of cordierite produce a coarse spotting in the wallrock - the spots are elongate parallel to the S1 fabric and thus must precede S1.
Pyrite and marcasite anhedra are scattered throughout the wallrock.
veins:- loellingite:- consumed by pyrite.
pyrite:- two types, massive and spongy. Massive occurs as cores within the spongy.
arsenopyrite:- consumes loellingite and pyrite (spongy and massive).
marcasite:- Crystalline and embayed margins in contact with pyrite. Marcasite consumes pyrite. Its relationship with arsenopyrite seems to suggest that arsenopyrite is growing at the expense of marcasite.
chalcopyrite & pyrrhotite:- small anhedral grains within loellingite and clearly consumed by that mineral.
quartz:- as the main gangue mineral and is classically crack-seal in form.
calcite:- is twinned and fractured. It occurs within a vein which truncates S1 sericite.

Interpretation:-
1. Sedimentation.
2. Hornfels - psuedomorphs of cordierite.
3. Deformation and S1 fabric.
4. Fracturing.
5. Crack-seal quartz.
6. Pyrrhotite and chalcopyrite.
7. Loellingite.
8. Fracturing.
9. Pyrite 1 (massive).
10. Fracturing.
11. Pyrite (spongy).
12. Marcasite.
13. Arsenopyrite.
14. Calcite.
15. S2.
16. S3.

Name:- Sandy siltstone; qtz-po-ccp-loel-py-marc-arsen vein; calcite vein; X3 deformations.

BD003c
Batman Hill, DDH BD003, 100.0m
Ref Nos:- A188
PTS - Section is missing.

Paragenetic description:- Clear gn in contact with ccp and surrounded by sph (pale yellow to white). Crystalline marcasite surrounded by py (is not a replacement). Corroded py core (looks very spongy) surrounded by subhedral massive py, and then ccp. Also massive py (subhedral surrounding marcasite). Ccp surrounding marcasite and pyrite. Sulphides seem to like precipitating near the bt. The sulphide fluid probably retrogressed, bt->chl+rutile, and this may have caused disequilibrium and sulphide precipitation.

BD006a
Batman Hill, DDH BD006, 147.25m
Ref Nos:- B006
PTS

Macroscopic:- quartz pyrrhotite vein in greywacke.

Microscopic:-
wallrock:- sandy siltstone. There are three fabrics as defined by the orientation of platey minerals:

1. S1 - 120° to the vein wall. It crosscuts quartz veins in the wallrock: the fabric is crosscut by the main quartz-sulphide vein, a chlorite vein and the S2 fabric.
2. S2 - parallel to fractures in the main vein and in the sulphides; the fractures are defined by granoblastic quartz.
3. S3 - weak fabric which sub-parallels the main vein. It crosscuts a chlorite vein.

i.e., qtz vein: cut by S1-S3.
crack-seal quartz vein: cut by S2 and qtz-chl-po-ccp fractures
qtz-chl-po vein: cut by S2 and S3.

veins:- quartz:- is of the crack-seal type with anhedral fibres lying sub-perpendicular to the vein wall.
pyrrhotite:- in fractures in the wallrock and the crack-seal quartz. Contacts with chalcopyrite are smooth and embayed (probably an equilibrium to consuming type texture).
chalcopyrite:- see pyrrhotite. Some chalcopyrite occurs as an accessory mineral that lies within fractures within pyrrhotite, and related to this is supergene alteration of pyrrhotite by marcasite.
talnakhite:- small 100 μm grains in contact with gold and bismuthinite in fractures within the crack-seal quartz. Consuming with respect to pyrrhotite and chalcopyrite.
gold:- 1-25 μm grains associated with talnakhite and bismuthinite.
bismuthinite:- see gold and talnakhite.
pyrite:- accessory mineral that lies within fractures within pyrrhotite and which is related to supergene alteration of pyrrhotite by marcasite.
marcasite:- supergene in type. The spongy or "birds eye" lamellae lie parallel to the S2 cleavage and may postdate it.
galena:- accessory mineral that lies within fractures within pyrrhotite and which is related to supergene alteration of pyrrhotite by marcasite.
calcite:- forms a calcite vein which is crosscutting with respect to the main vein and S1 and S2 fabrics.

Interpretation:-
1. Sedimentation.
2. Fracturing.
3. Quartz veining.
4. Deformation and S1 fabric.
5. Fracturing.
6. Crack-seal quartz.
7. Fracturing.
8. Quartz, chlorite, pyrrhotite (& chalcopyrite).
9. Chalcopyrite.
10. Fracturing.
11. Au, talnakhite, bismuthinite.
12. S2.
13. Calcite veining.
14. Supergene marcasite, pyrite, galena and chalcopyrite.
15. S3.

Name:- sandy siltstone; quartz-po-ccp-Au-tal-bism vein; calcite vein; X3 deformations.

BD006b
Batman Hill, DDH BD006, 101.3m
Ref Nos:- B005
PTS

Macroscopic:- quartz-sulphide vein in sandstone greywacke. A fabric is defined cutting the vein and sulphides.

Microscopic:-
wallrock:- composed of occasional quartz clast to 75 μm, in a matrix of equant quartz (25 μm), sericite and chlorite (20 μm long plates), equant hematite masses (10 μm) and occasional anhedra of chalcopyrite (250 μm). The chlorite and sericite laths, and some quartz clasts, define a fabric which is sub- perpendicular to the wall of the main vein. (==> sandy siltstone).

vein 1:- crack-seal fibres line the vein wall and are crosscut by sulphides and calcite. The sulphides consist of sphalerite, chalcopyrite, pyrrhotite, pyrite and rare arsenopyrite. Vein 1 is crosscut by the wallrock fabric.

pyrrhotite:- as anhedral masses within calcite, crack-seal quartz, pyrite and chalcopyrite. It appears to be consumed by chalcopyrite (may be coeval) and pyrite 1.

pyrite 1:- is massive, anhedral bodies which are fractured: the fractures are filled with calcite. Pyrite 1 is surrounded by fine anhedral-subhedral pyrite 2, giving pyrite1 a fluffy margin.

arsenopyrite:- sub-crystalline and consumes pyrite 1 and 2 and marcasite.

marcasite 1:- is crystalline in from and consumes pyrite 1 and 2 although 1 large crystal is partly enclosed by pyrite 1 and surrounded by pyrite 2.

marcasite 2:- supergene alteration of pyrite 1 and 2, pyrrhotite and chalcopyrite.

chalcopyrite:- found in contact with pyrrhotite which it seems to embay. This may imply equilibrium. Rare grains within arsenopyrite are strongly embayed and reacting out. Chalcopyrite is also associated with late veins of quartz and chlorite which are post-S2.

sphalerite:- found as rare euhedra-subhedra which contact chalcopyrite and pyrrhotite. It is deep brown in colour and contains tiny inclusions of chalcopyrite. Where it contacts chalcopyrite, the margins are straight and sub-crystalline.

calcite:- lines fractures within crack-seal quartz and pyrite. It is fractured itself: pyrite occurs within the fractures (Py 2).

vein 2 and 3:- chlorite-pyrite-calcite vein: the chlorite lines the vein wall and/or occurs as a selvedge to the vein wall. This vein crosscuts a quartz-chlorite-chalcopyrite vein (vein 3). Vein 2 is crosscut by the wall rock fabric. These veins crosscut vein type 1.

<u>Interpretation</u>:-

1. Sedimentation.
2. Fracturing.
3. Crack-seal quartz veining.
4. Fracturing.
5. Pyrrhotite + chalcopyrite.
6. (Some crystalline marcasite?).
7. Pyrite 1 replaces pyrrhotite and chalcopyrite.
8. Pyrite 2.
9. Marcasite 1 replaces pyrite 1 & 2, and chalcopyrite.
10. Arsenopyrite.
11. S2 fabric.
12. Fracturing.
13. Quartz, chlorite and chalcopyrite vein.
14. Chlorite, pyrite and calcite vein.
15. Marcasite supergene alteration.

<u>Name</u>:- sandy siltstone; qtz-po-ccp-py-mar-ars vein; qtz-chl-ccp vein; chl-py-calc vein.

BD006c
Batman Hill, DDH BD006, 119-120m.
Ref Nos:- B009
PTS

Macroscopic:- mottled dark grey and a greenish-grey sediment cut by a sulphide rich quartz vein.

Microscopic:-
wallrock:- the altered siltstone is composed of angular detrital fragments of quartz and lithic fragments (0.1 mm) in a matrix of biotite sericite, and quartz. Sulphides disseminated through the rock include pyrite, arsenopyrite and chalcopyrite.
Sericite and chlorite define a mineral elongation which is sub-perpendicular to the vein wall (S1). Fine trails and fractures containing granoblastic quartz crosscut the vein and may define a second fabric (S2).
Sericite and chlorite psuedomorphs of cordierite indicate that the sediment had been hornfelsed prior to the development of the fabrics.
Vein:- in the vein, coarse grained quartz (4 mm long) predominates. The elongate nature of the quartz crystals is indicative of crack-seal quartz development syntaxial to the vein wall. The fibres are brecciated and infilled with quartz, sulphides and calcite. Sulphides include pyrrhotite, chalcopyrite, and marcasite. Marcasite is of the supergene form and late. Late chlorite-chalcopyrite-calcite veins crosscut the wallrock, fabric and main vein. The chlorite is syntaxial.

Interpretation:-
1. Sedimentation.
2. Hornfelsing - cordierite psuedomorphs.
3. Deformation - S1 fabric and spot elongation.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Pyrrhotite and chalcopyrite.
8. Fracturing.
9. S2 fabric.
10. Fracturing.
11. Chl-ccp-cal vein.
12. Marcasite - supergene.

Name:- sandy siltstone and muddy siltstone; qtz-po-ccp-mar-vein; chl-ccp-cal vein.

BD006g
Batman Hill, DDH BD006, 189.8-189.9m.
Ref Nos:- B013
PTS

Macroscopic:- a quartz-sulphide vein in a massive, dark greywacke with greenish-grey spots.

Microscopic:-
wallrock:- the wallrock is composed of sericite, quartz, biotite and chlorite (all ~ 20 μm in size) with two spot types (1 mm in size) scattered throughout. These probably represent psuedomorphs after cordierite. Spot type 1 is entirely composed of quartz, sericite, and chlorite, and are weakly flattened parallel to the S1 fabric. They are crosscut by spot type 2 which is almost entirely composed of chlorite.
Chlorite and sericite define two fabric orientations: a weak fabric lying 45° to the vein wall (S1); a strong fabric which is perpendicular to the vein wall and which crosscuts the vein (call S2).
Marcasite and pyrite are disseminated throughout the wallrock.

Vein:-quartz:- crack-seal type quartz with fibres orientated sub-perpendicular to the vein wall.
pyrrhotite:- heavily fractured and consumed by pyrite and marcasite (crystalline).
pyrite:- of 3 types. Spongy pyrite (py 2) surround sub-rounded massive pyrite cores (py 1) which is surrounded by mega-framboidal pyrite (py 3). Pyrite 3 contains inclusions of arsenopyrite and marcasite.
marcasite:- consuming pyrite and pyrrhotite. It occurs as tabular crystals which are consumed by arsenopyrite and thus must predate that sulphide.
arsenopyrite:- contains numerous tiny quartz inclusions (~ 2 μm in size). Some arsenopyrite is enclosed by pyrite 3 and thus must predate this sulphide.
Calcite-chlorite-pyrite vein:- is crosscutting with respect to the fabrics and wallrock spots.

Interpretation:-
1. Sedimentation.
2. Hornfels - cordierite spots type 1.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Pyrrhotite
8. Fracturing.
9. Pyrite 1 (massive).
10. Fracturing.
11. Pyrite 2 (spongy).
12. Marcasite.
13. Arsenopyrite - syn to post marcasite.
14. Pyrite 3 (framboidal).
15. Deformation and S2 fabric - syn veining and hornfelsing (spot 2).
16. Cal-py-chl vein.

Name:- Hornfelsed medium siltstone; Qtz-po-py-mar-ars vein; Cal-py-chl vein; X2 hornfelsing and X2 deformations.

BD008a (1-3)
DDH BD008, 98-99 m.
Ref Nos: A167
PTS

Macroscopic:- calcite-galena-sphalerite-pyrite-arsenopyrite vein.

Microscopic:-
marcasite:- (5%) anhedral to euhedral masses of marcasite in rays, i.e. reniform texture; marcasite is intimately associated with pyrite in the flower structure.
pyrite:- (5%) anhedral to euhedral masses of pyrite in rays and cauliflowers which commonly nucleate on marcasite, i.e. reniform texture; pyrite is intimately associated with marcasite in flower structures.
sphalerite:- (60%) occurs in two textural types. The first is as follows - a central core of calcite containing sphalerite inclusions is surrounded by zones of sphalerite. These zones show an increase or decrease in iron content, each zone being a deeper brown or lighter brown in colour respectively. The browner the zones, the greater the number of chalcopyrite blebs within that zone, although very black zones contain blebs of pyrrhotite. Some almost black zones are quite porous and it is possible that these gaps were once filled, perhaps with calcite. It may have been removed during later sphalerite or calcite precipitation. The last sphalerite to be deposited is quite pale in colour. Thus there exist cycles of sphalerite, sphalerite/ chalcopyrite, and sphalerite-chalcopyrite-calcite.
The sphalerite gives way to a zone of calcite, which in turn, gives way to a zone of arsenopyrite/pyrite, calcite, sphalerite in cycles, and finally to calcite.
The second sphalerite type is that as described below (see galena).

galena:- (10%) anhedral; has a fish bone or feather structure and is intimately associated with euhedral calcite. Surrounding this mass, is a zone of yellow, orange, then yellow sphalerite. This is enclosed by calcite. The whole structure is star shaped, each arm of the star representing one fish bone structure. Exhibits evidence of post emplacement strain, i.e., pluck marks as caused by polishing suggest that the galena lattice is kinked.

chalcopyrite:- (tr up to 1%) subhedral to anhedral crystal. There is possibly an early type (pre-galena) beside that associated with sphalerite.

calcite:- (20%) as described above. It is the sole gangue mineral. It builds coarse rhombs up to 5 mm in size. It exhibits undulose extinction with subgrain development which would suggest that some post emplacement strain has occurred.

Interpretation and history:-

1. Chalcopyrite?
2. Star shaped structures- galena/calcite
   sphalerite - yellow, orange, yellow
   calcite.
3. Fracturing.
4. Sphalerite zonation (sp, sp/ccp/po or sp/ccp/cal).
5. Calcite.
6. Colloidal marcasite/pyrite.
7. Calcite.
8. Sphalerite.
9. Calcite.
10. Weak deformation (S2?).

Name:- Calcite-sulphide assemblage.

BD008c
DDH BD008, 90.9 m
Ref Nos: B27
PTS

Macroscopic:- Quartz-pyrite vein in greywacke, cut by pyrite-chlorite-quartz vein and quartz-chalcopyrite vein.

Microscopic:-

wallrock: quartz clasts:- angular to subrounded in a quartz sericite matrix of sandstone. Generally fine grained with dispersed occasional small chlorite clots, possibly after cordierite. The presence of fine disseminated chalcopyrite is noted. The chalcopyrite and chlorite appear to be later and occur as infill. Rutile is common throughout, as are clusters of zircons. There is a general fabric alignment (S1) of sericite and oblong quartz clasts which sub-parallels and cuts across bedding . The fabric lies at an angle of 45° to the vein wall, S2 lies some 60° to the vein wall and dissects the sulphides.

Veins:

type A:- quartz-pyrite-arsenopyrite vein.

pyrrhotite:- anhedral po to 12.5 μm has contact margins with pyrite 1 which are curved and smooth ==> py after po.

pyrite 1:- anhedral - subhedral pyrite to 100 μm. This is surrounded by euhedral to subhedral marcasite and anhedral pyrite 2.

marcasite:- euhedral to subhedral grains to 50 μm in size. Surrounds pyrite1 and occasionally as < 1 μm masses which erupt into laths contacting pyrite. Marcasite also occurs as fill to fractures in pyrite 1.

pyrite 2:- fine anhedra to 5 μm. They coat pyrite 1 giving it an anhedral or subhedral form.

quartz:- lines the vein walls; has an elongate nature with fluid inclusion trails perpendicular to sub-perpendicular to the elongation direction; I have a desire to interpret this quartz as crack seal quartz; small quartz grains at the margins of the vein walls seem to represent syntaxial growth of quartz where new quartz has initially grown in optical continuity with the wall quartz.

quartz fluid incluison trails (A):- trails parallel to vein walls; very small (>3 μm), 2 phase and one phase inclusions; there is no uniformity in shape or size or in L:V ratios from one trail to another trail, nor within any one trail; orientation and nature would suggest they are crack seal type.inclusions; trails run across quartz grain boundaries and thus are secondary with respect to that boundary.

quartz fluid inclusion trails (B):- trails are not parallel to the walls; 3 basic orientations:-

(i) at angles between 40° to 70° to the vein wall; one phase (looks like CO_2 vapour) inclusion trails that cut quartz vein boundaries and cut fluid inclusion trails (A); trails show inclusions decreasing in size at either end of the trail (like a string of beads) but all inclusions are uniform in L:V ratios and general character.

(ii) as for B(i) but orientated parallel to the vein walls; only two such trails seen.

(iii) as for B(i) but with a random orientation to the trails with respect to the vein walls; the trails converge at some site, the sites exhibiting stressed quartz.

carbonate:- full of fluid inclusions which were probably 2 phase [section has been over-cooked during preparation and most fluid inclusions have decrepitated).

chlorite:- micro-veins, but seen as a minor alteration phase around the vein wall.

biotite:- as for chlorite.

type B:- quartz vein.

quartz:- is of the crack seal type with quartz fibres perpendicular to sub-perpendicular to the vein wall. Fluid inclusions are >3 μm and are parallel but mostly oblique to the vein wall. With respect to vein A, the fluid inclusion trails are vein wall parallel. No sulphides are associated with this vein.

type C:- chlorite vein.

type D:- carbonate vein. - this vein is cut by type C chlorite vein.

type F:- carbonate vein (again) - chlorite lines some of the vein walls but also goes around some carbonate grain boundaries. This suggests that chlorite postdates carbonate precipitation. There is some association of the carbonate with chalcopyrite and pyrite. This vein crosscuts Vein A, S1 and S2 and thus must be late.

type G:- marcasite-sphalerite-carbonate-chlorite vein. The chlorite lines the vein wall and occurs as an alteration halo around the vein. The marcasite lines the wall and is fine grained. This gives way to clear calcite rhombs. The rhombs give way to calcite and tiny anhedral sphalerite grains (20 μm). Finally calcite becomes dominant, i.e.,

marcasite ==> calcite ==> calcite-sphalerite ==> calcite

Chlorite in the wallrock is probably associated with arsenopyrite.

A chlorite, chalcopyrite, pyrrhotite, sphalerite, calcite vein is clearly crosscut by a chlorite vein.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Pyrrhotite + chalcopyrite.
8. Pyrite 1 - consumes pyrrhotite + chalcopyrite.
9. Fracturing.
10. Pyrite 2 (spongy).
11. Marcasite (crystalline).
12. Fracturing.
13. Calcite and chlorite.
14. Deformation and S2 fabric.
15. Chlorite vein.
16. Calcite-chalcopyrite-pyrite vein (type F).

Name:- Hornfelsed muddy sandstone; Quartz-pyrrhotite-pyrite-marcasite; Chlorite vein; Calcite-chalcopyrite-pyrite vein.

BD013a
Batman Hill, DDH BD013 - 113.05 m.
Ref Nos:- B033
PTS

Macroscopic:- quartz-pyrite-marcasite-chalcopyrite vein which crosscuts a siltstone. A weak fabric is defined in the vein by crosscutting fractures which lie perpendicular to the vein wall.

Microscopic:-
wallrock:- is composed of angular quartz clasts (matrix supported) in a matrix of quartz, sericite, chlorite rutile and accessory zircons. Pyrrhotite and chalcopyrite anhedra to subhedra are scattered throughout. Rare bismuth masses contact pyrrhotite that is consumed by pyrite and marcasite.
The alignment of sericite and chlorite defines 2 fabric orientations; a strong fabric (S1) and a weak fabric (S2) which overprints S1. S2 crosscuts the vein (i.e., it parallels fractures in the vein which are assumed to be the vein equivalent of this fabric).
Vein:- predominantly composed of syntaxial crack-seal quartz fibre which is heavily fractured. The fibres contain trails of tiny (<1 μm) fluid inclusions. Fracturing of the crack-seal vein probably facilitated open space fill and the growth of the clear quartz and then the pyrrhotite. Some granoblastic quartz is probably related to late stress during the formation of the S2 cleavage.
quartz:- beside the crack-seal quartz, clear quartz is associated with pyrrhotite precipitation. The clear quartz does not contain fluid inclusions (excluding 2° inclusions) and appears to be in equilibrium with the pyrrhotite.
pyrrhotite:- anhedral masses in fractures within crack-seal quartz. Reacting out to marcasite and quartz.
chalcopyrite:- anhedral masses in fractures within crack-seal quartz. Contacts and embays pyrrhotite and thus probably postdates the sulphide.
sphalerite:- Fe rich, dark orange grains to 100 μm which embay chalcopyrite contain tiny blebs of chalcopyrite (< 2 μm).
bismuth:- occasional anhedra in the wallrock and within blebs in the crack-seal quartz. Is associated with bismuthinite and gold, and lies adjacent to, or in fractures which crosscut quartz, chalcopyrite, pyrrhotite and sphalerite. Thus they are late. Has some association with sphalerite.
gold and bismuthinite:- as for bismuth.
calcite:- lies within a fracture and is crosscutting with respect to crack-seal quartz and sulphides.

Interpretation:-
1. Sedimentation.
2. Deformation and strong S1 fabric.
3. Fracturing.
4. Crack-seal quartz.
5. Clear quartz and pyrrhotite.
6. Fracturing.
7. Chalcopyrite consuming pyrrhotite.
8. Fracturing.
9. Fe rich sphalerite: consumes chalcopyrite.
10. Fracturing.
11. Bismuth, bismuthinite and gold - within quartz, chalcopyrite, pyrrhotite and sphalerite.
12. Deformation and weak S2 fabric (contiguous with mineralisation).
13. Fracturing.
14. Calcite vein.

Name:- Quartz-po-Au-bis-bism-sph vein; Calcite vein; X2 deformation.

BD016c
Batman Hill, DDH BD016, 151.45m.
Ref Nos:- B043
PTS - Section is damaged.

Macroscopic:- Quartz-pyrrhotite vein in siltstone which contains a strong fabric sub-parallel to the vein wall (~25°, call S1). The fabric does not cut the vein sulphides. A spaced fracture fabric (call S2) does not cut the vein and is sub-perpendicular to the vein wall.

Microscopic:-
wallrock:- composed of quartz-biotite, sericite and chlorite (15 μm) ===> medium siltstone. Sericite and chlorite psuedomorphs after cordierite resolve a spotted texture in the wallrock. The spots are elongate parallel to S1 fabric which is strong at this scale. S1 is cut by a chl-po-ccp vein (which is cut by a S1 parallel chlorite vein).
(Bt? is synchronous to vein formation or peak S1 since it parallels the S1 fabric.)
Chalcopyrite and pyrrhotite are in equilibrium (embayed) and are disseminated throughout the wallrock and postdate the S1 cleavage since, although they form elongate masses parallel to S1, they are not deformed by this fabric, i.e., the masses are single grains as such. Chalcopyrite embays pyrrhotite as often as pyrrhotite embays chalcopyrite. Accessory supergene marcasite is found throughout.
vein:- quartz:- main gangue mineral and is heavily brecciated by sulphides. It is crack-seal in nature, syntaxial-anataxial to the vein wall, and contains occasional rutile needles which parallel the S1 cleavage. The quartz is possibly pre- to syn-S1.
calcite:- euhedral crystals found within brecciated sulphides. In contact with orange coloured sphalerite. Is late and crosscuts S2 parallel fractures and fabric.
pyrrhotite:- (see wallrock) consumes and is consumed by chalcopyrite.
chalcopyrite:- (see wallrock) consumes and is consumed by pyrrhotite.
marcasite:- supergene lamellae type. The lamellae have random orientation and thus postdate S2.
arsenopyrite:- accessory euhedral overgrowth of pyrrhotite. Clearly located along a fracture in pyrrhotite and through crack-seal quartz.
talnakhite:- 15-50 μm grains which consume pyrrhotite. Intimate association with Au, bismuthinite, and bismuth.
bismuth:- Intimate association with Au, bismuthinite, and talnakhite.
bismuthinite:- Intimate association with Au, talnakhite, and bismuth.
gold:- Intimate association with talnakhite, bismuthinite, and bismuth. Occur as 25-250 μm grains.
N.B. The Au, bismuth, bismuthinite and talnakhite fractures crosscut the S1 fabric in the wallrock, and in pyrrhotite and chalcopyrite (NO DOUBT).

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - cordierite spot.
3. Anataxial quartz vein.
4. Deformation and S1 fabric - elongation of spots.
5. Fracturing.
6. Chl-po-ccp vein.
7. Arsenopyrite.
8. Fracturing.
9. Bismuth, bismuthinite, talnakhite, and Au.
10. Deformation and S2 fabric - deformation of sulphides.
11. Chlorite vein.
12. Calcite-sphalerite vein.
13. Supergene alteration and marcasite.

Name:- Medium siltstone (X2 deformation); Qtz-po-ccp-arsen-tal-bi-bis-Au vein; Chlorite vein; Calcite vein.

BD018a
Batman Hill, DDH BD018, 88.1m.
Ref Nos:- B048
PTS - Section is missing.

Macroscopic:- Quartz-sulphide vein in a sandstone greywacke. The vein is cut by a fabric near perpendicular to the vein wall. The fabric has intensely fractured the sulphides and veins.

Microscopic:-
wallrock:- consists of poorly sorted angular matrix supported quartz and quartzite clasts (0.5 mm) in a matrix of quartz, chlorite, sericite, biotite and accessory zircons. The biotite is coarser towards the margins of the vein however it becomes somewhat chloritised leaving Ti relics behind. Rutile masses and grains, and occasional anhedral pyrite and pyrrhotite grains are scattered throughout.
Two fabric alignments are evident in section: a weak fabric which is near perpendicular to the vein wall. This fabric is parallel to a fracture fabric in the sulphides and must therefore postdate the sulphides (S2). A stronger, early fabric (as defined by the orientation of clasts and by the alignment of platey minerals) lies at 45 ° to the vein wall. Biotite also displays this alignment which would suggest that biotite is syn- to pre-S1. The S1 fabric does not crosscut the vein and thus must predate the vein (S1).
veins:- chlorite vein:- narrow vein of euhedral, dark green chlorite which crosscut the main vein and S1 and S2 fabrics and thus must postdate them. Within the main vein, the chlorite commonly forms half spherulites.
quartz-sulphide vein:-
quartz: minor elongate syntaxial quartz fibres.
marcasite:- the main sulphide of the vein. Is consuming of pyrite, loellingite, and arsenopyrite. Forms lamellae and blocks and is supergene.
gold:- within inclusions along fractures in crack-seal quartz and arsenopyrite. Largest grains are 40 μm in size. Intimately associated with bismuthinite.
bismuthinite:- within inclusions along fractures in crack-seal quartz and arsenopyrite. Intimately associated with gold.
pyrite:- massive in nature and consumed by arsenopyrite and marcasite.
loellingite:- consumed by marcasite and heavily fractured arsenopyrite.
chalcopyrite:- anhedral and partly consumed by sphalerite.
iss (talnakhite):- accessory mineral which is consumed by sphalerite.
pyrrhotite:- accessory mineral in arsenopyrite (but not loellingite). Contacts iss cubanite with smooth curved margins and is a co-precipitate.
iss (cubanite):- accessory anhedra in arsenopyrite. Co-precipitate with pyrrhotite.
calcite:- occurs within a vein which crosscuts the fabrics present, and thus is late.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - biotite development.
3. Deformation and S1 fabric - alignment of platey minerals.
4. Fracturing.
5. Crack-seal quartz.
6. Iss (cubanite)-iss (talnakhite)-pyrrhotite.
7. Loellingite.
8. Arsenopyrite.
9. Fracturing.
10. Au-bismuthinite-talnakhite.
11. Deformation and S2 fabric.
12. Fracturing
13. Calcite and sphalerite veining.
14. Marcasite (supergene).

Name:- Sandy siltstone; Quartz-iss(cub)-iss(tal)-po-loel-arsen-Au-bismuthinite-talnakhite; X2 deformations; calcite and sphalerite.

BD021b
Batman Hill, DDH BD021, 117.0 m.
Ref Nos:- B052
PTS

Macroscopic:- Quartz-pyrite-arsenopyrite vein. Sulphides lie within fractures in the quartz and they are fractured themselves.

Microscopic:-
wallrock:- INSUFFICIENT PRESENT.
vein:- quartz:- is of the crack-seal type and syntaxial to quartz in the vein wall. Single crystals are up to 1 cm long and 0.5 cm wide. They are heavily fractured and crosscut a calcite vein. They have serrate margins indicating some post- emplacement stress and re-equilibration along crosscutting fractures resolves granoblastic quartz. Sulphides lie within fractures in the quartz.
calcite:- occurs within fractures which crosscut the crack-seal quartz, sulphides, and the vein wall. Thus they must postdate the vein and sulphides. The array of calcite filled fractures, in part, has produced a jig-saw breccia. The fractures are roughly parallel to sub-parallel or anastomosing. Calcite crystals are undeformed and crosscut granoblastic quartz.
pyrite:- is the main sulphide present. Occurs as anhedral, massive patches which are heavily fractured and, in part, suffering supergene alteration to marcasite.
marcasite:- supergene alteration with "bird's eye" texture. Marcasite reaction is from most sulphides especially along fractures in pyrite. The lamellae resolve chalcopyrite, galena, and pyrite which must be supergene in nature. Some supergene marcasite is crosscut by calcite veins suggesting some supergene calcite (blocky type) is pre-calcite in age.
chalcopyrite:- minor sulphide which occurs in 2 forms:-
1. Along fractures in crack-seal quartz together with pyrrhotite.
2. As a supergene mineral.
Type 1 is anhedral and has suffered alteration on its margin to covellite and/or marcasite alteration. Rare grains indicate that chalcopyrite is consuming of pyrrhotite, although pyrrhotite consumption of chalcopyrite occurs as often as chalcopyrite consumption of pyrrhotite.
Type 2 is supergene and intimately associated with marcasite.
pyrrhotite:- minor anhedral sulphide that occurs along fractures in the crack-seal quartz together with chalcopyrite. Some embayed grains are found within pyrite suggesting the pyrrhotite predates pyrite.

Interpretation:-

1. Sedimentation.
2. Fracturing.
3. Crack-seal veining.
4. Fracturing.
5. Chalcopyrite + pyrrhotite (equilibrium texture).
6. Fracturing.
7. Pyrite (massive).
8. Granoblastic quartz (==> Deformation?)
9. Marcasite (supergene).
10. Fracturing.
11. Calcite veining.
12. Marcasite (supergene)-ccp-gn-py and covellite alteration.

Name:- Qtz-po-ccp-py vein; calcite vein.

BD023a

Batman Hill, DDH BD023, 41.90m.
Ref Nos:- B059
PTS - Section is oxidising quickly.

Macroscopic:- Heavily weathered sulphide vein in sandstone greywacke.

Microscopic:-

wallrock:- Quartz clasts (50 μm) which are matrix supported in a fine matrix (<15 μm) of Fe-oxides, accessory zircons, quartz, sericite and chlorite (===> sandy siltstone).

Chlorite and sericite define two fabric orientations:- (i) sub=parallel to the vein wall (ii) ~ 45° to the vein wall. Type (ii) chlorites crosscut type (i) (call S2 and S1 respectively).

vein:- for those which crosscut the wallrock, alteration means that hematite/goethite are the main minerals. Marcasite and pyrite are the main sulphides; marcasite the dominant phase. It occurs in two forms:-

1. Crystalline marcasite which embays pyrite. The orientation of these crysts define a weak fabric (under crossed polars) which parallels the S2 fabric in the wallrock. Clearly the fabric must postdate the sulphide.

Some crystals of this sulphide lie within a sea of pyrite indicating that some pyrite postdates marcasite.

2. Supergene marcasite which embays crystalline marcasite and pyrite. This marcasite contains numerous tiny quartz inclusions and exhibits "bird' eye" texture.

With respect to the pyrite, two forms are present. Pyrite 1 is massive and devoid of quartz inclusions. Pyrite 2 is spongy (it looks this way because the euhedra of pyrite are very small and intergrown).

With respect to pyrite and marcasite (crystalline), there is evidence of:-

1. Crystalline marcasite embaying pyrite 1 and 2.
2. Pyrite 1 and 2 embay crystalline marcasite.

This would indicate a complex history of marcasite and pyrite intergrowth, and would suggest sulphide precipitation from a fluid which was fluctuating in pH.

Lastly the sulphides are heavily brecciated and weathered along fractures producing interesting patterns of hematite alteration.

Post-sulphide faulting along the margin of the vein wall, is indicated from the crushed nature of sulphide, vein quartz, and wallrock material.

Quartz as the only gangue mineral is clear and rounded. It is located within the brecciated zone.

Interpretation:-
1. Sedimentation.
2. Deformation and S1 fabric (vein parallel).
3. Fracturing.
4. Vein emplacement.
5. Marcasite => pyrite => marcasite => pyrite => marcasite.
6. Deformation and S2 fabric (and faulting?).
7. Marcasite (supergene).
8. Fracturing.
9. Hematite/goethite.

Name:- Sandy siltstone; Mar-py vein.

BD027a
Batman Hill, DDH BD027, 172.20m.
Ref Nos:- B062
PTS

Macroscopic:- Quartz-pyrrhotite vein in sandstone greywacke. Sulphides are disseminated throughout the wallrock.

Microscopic:-
wallrock:-composed of two units:-
(i) Quartz clasts to 50 μm in a matrix of quartz (25 μm in size), sericite, chlorite, and needles of tourmaline or rutile (too small to tell) (=> sandy siltstone);
(ii) Sericite, chlorite, quartz (20 μm in size) (=> shale).
The sericite and chlorite define two fabric orientations:-
(i) A strong fabric which lies sub-perpendicular to the vein wall (S1);
(ii) A weak crosscutting fabric which lies at 45° to the vein wall (S2). Crosscutting relationship is based on evidence that S1 sericite is crosscut by S2 sericite.
Spotting in the wallrock is also of two types:-
(i) As defined by a compositional layering, i.e., there are S1 parallel ovoid zones which contain less sericite than the zones without. The spots are probably ex-cordierite. The S1 and S2 fabrics trangress these spots.
(ii) As defined by anhedral pyrrhotite and chalcopyrite (also marcasite which is a supergene alteration mineral) and chlorite plates. The presence of some S2 parallel sericite within these spots would indicate they are pre-S2, while the sulphides would indicate they are syn-mineralisation.
vein:- quartz:- main gangue mineral and is heavily fractured and stressed. Are really clasts since they consist of composite grains. These were possibly crack-seal quartz.
calcite:- unstressed minor calcite occurs in parallel to anastomosing fractures which crosscut the sulphides and S1 and S2 fabrics in the wallrock. At one, it runs coincident to a chl-po-ccp vein, however, it does postdate S2.
pyrrhotite:- is the main sulphide mineral in the wallrock and vein. By and large, the pyrrhotite is spongy in form, containing many tiny inclusions of quartz., However, massive pyrrhotite also occurs and this is surrounded by the spongy pyrrhotite type.
Therefore:- po 1 (massive) :- isotropic form, not brecciated.
po 2 (spongy):- strongly anisotropic and brecciated.
Clearly only one pyrrhotite mineralisation event is required, however there must have been brecciation of the pyrrhotite syn- to post mineralisation.
chalcopyrite:- embays pyrrhotite 1 and 2 although it tends to line the po 1 clasts and consume the po 2 form (although po 2 is also seen to consume ccp).
marcasite:- supergene alteration of po and ccp. Displays blocky texture and is crosscut by calcite veins. Its relationship to S2 is not clear.

Interpretation:-
1. Sedimentation.
2. Hornfels - spot 1 (ex-cordierite).
3. Deformation and S1 fabric - elongation of spot type 1.
(Spot 2 must predate mineralisation but postdate S1).
4. Fracturing.
5. ?Crack-seal quartz.
6. Fracturing.
7. Massive pyrrhotite (po 1).
8. Fracturing.
9. Po2-ccp-chl-qtz.
10. Fracturing - all sulphides are fractured.
11. Deformation and S2 fabric.
12. Marcasite (blocky type and recrytallised supergene).
13. Fracturing.
14. Calcite vein.

Name:- Sandy siltstone; Qtz-po1-po2-ccp-chl vein; X2 deformation; X2 hornfelsing.

BD027e
Batman Hill, DDH BD027 - 333.20 m.
Ref Nos:- B066
PTS

Macroscopic:- quartz-pyrrhotite-chalcopyrite vein.

Microscopic:- wallrock:- 0.5 mm, matrix supported, poorly sorted, quartz clasts in a matrix of quartz, chlorite, sericite and opaques. (==> siltstone or sandy siltstone). Rutile needles are present throughout. Chlorite and sericite define a strong fabric (probably S1) which does not cut the main vein and which is ~ 60° away from the fabric (S2) which crosscuts the sulphides. Pyrrhotite and rutile are disseminate throughout.
vein:- the development of crack-seal quartz is evident. The quartz has been stressed in part such that quartz subgrain development has preceded. Crack-seal quartz gives way to open space fill of, initially clear quartz, and then to pyrrhotite.
pyrrhotite:- fractured, occurs as fill to fractures within crack-seal quartz and the wallrock.
chalcopyrite:- accessory mineral which contacts pyrrhotite with smooth margins (embayed). Occurs within fractures within crack-seal quartz and pyrrhotite.
marcasite:- accessory mineral. Fine tabular anhedra which consume pyrrhotite. Are lamellar in from ("birds eye" texture) and indicative of supergene alteration.
arsenopyrite:- euhedral, accessory mineral in pyrrhotite , contains an inclusion of po.
calcite:- crosscuts wallrock fabrics, sulphides, vein and vein fabrics (==> late phase).
chlorite:- in crosscutting fractures in which it is spherulitic in form.

Interpretation:-
1. Sedimentation.
2. Deformation and S1 fabric.
3. Fracturing.
4. Crack-seal quartz.
5. Fracturing
6. Quartz & pyrrhotite.
7. Chalcopyrite.
8. Arsenopyrite.
9. Deformation and S2 fabric (as seen crosscutting the quartz sulphide vein).
10. Fracturing.
11. Calcite & chlorite (spherulitic).
12. Marcasite (supergene).

Name:- Sandy siltstone; Quartz-po-ccp-ars; X2 deformations; Calcite and chlorite vein.

BD056b
Batman Hill, DDH BD056 - 85.3 m.
Ref Nos:- B070.
PTS

Macroscopic:- pellet in sediment.

Microscopic:-
wallrock:- fine silty type shale.
fuchsite/biotite:- (50%) < 10 μm in size, subhedral to anhedral, generally distributed throughout the wallrock material and occurs as clumps (= brown spotting of the wallrock).
quartz:- (50%) < 10 μm in size, anhedral and clearly detrital in origin.
pellett:-consists of numerous concentric zones.
1. qtz (50%), chl, musc, py), ~ 10 μm grains.
2. chl (30%), qtz, musc, zircons, ~ 10 μm grains.
3. chl (30%), musc, qtz, zircons.
4. musc (50%), qtz, chl.
5. chl (70%), musc, qtz.
6. chl (90%), musc, qtz.
7. chl (65%), qtz.
8. chl (60%), qtz, musc.
9. qtz (30%), chl (30%), opaques (30%), sedimentary fragments (10%). Anhedral opaques are pyrite.

Interpretation:- Fine grain aggregate of mud layers around fine sand/mud/rock fragment core. Clearly detrital in origin and not concretionary. Biotite in the wallrock would suggest hornfelsing of the sediments.

1. Sedimentation.
2. Hornfelsing - biotite.

Name:- Pellet in hornfelsed shale.

BD056c
Batman Hill, DDH BD056 - 101.4 m.
Ref Nos:- B070.
PTS

Macroscopic:- sediment with pellett.

Microscopic:-
Area 1:- consists predominantly of quartz, biotite, chlorite grains in equal proportions. Individual grains are < 8 μm in size. Layers are defined by an increase in chlorite and biotite relative to quartz grains (----> compositional layering). Spotting is associated μm) py and hematite grains are distributed throughout. Spots are 200 μm in diameter and are elongate sub-parallel to compositional layering. The elongation is parallel to a strong fabric (S1) which is also sub-parallel to bedding. A weak fabric (S2) crosscuts S1 as defined by overgrowths of one sericite orientation over another. Spots and layering are cut by chlorite/quartz veins. Base of the bed contains recrystallised rock fragments which are overprinted by arsenopyrite, pyrite & chalcopyrite (not clear if it is related to chl/qtz veins) and may indicate mineralisation after brecciation (faulting). (==> fine silty mudstone)

Area 2:- consist predominantly of clasts of hornfelsed fine silty mudstone in a matrix of mudstone. Clasts are matrix supported. Micro-bedding and clast imbrication indicates younging direction, as does the bed compositional changes related to turbidite deposition. Clasts are angular to subrounded. Spotting within clasts is not dissected indicating that they are post depositional. This bed is cut by chlorite/quartz veins.

Area 3:- predominantly sst clasts in a matrix of mudstone.

Area 4:- predominately sandstone, quartz, mudstone and hematite detritus in a matrix of mudstone.

Area 5:- pellett:- fine silty mudstone core surrounded by (a) qtz dominant layer and (b) chl dominant layer.

All beds and the pellett are dissected bt qtz/chlorite veins and all opaques are bed associated, i.e., py-ars-ccp is restricted to the clasts at the base of bed (1), and hematite is restricted to the base of bed (4).

Interpretation:- Pellett overlain by coarse sandstone turbidite, fine sandstone turbidite, coarse mudstone, turbidite and mudstone, hornfelsed to produce spotting, and deformed by S1 fabric. Sedimentary units, the spots, and the fabric are dissected by qtz-chlorite veins which grow syntaxial to the vein wall, i.e., pellett=> bed => hornfelsing => S1 => S2 => qtz/chl veining.

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Deformation and S2 fabric.
6. Quartz-chlorite vein.

Name:- pellet and sediment which are hornfelsed; S1 fabric; quartz-chlorite vein.

BD056d

Batman Hill, DDH BD056 - 114.5 m.

Ref Nos:- B070

PTS

Macroscopic:- spotted shale crosscut by veins.

Microscopic:-

Wallrock:-

quartz:- anhedral grains ~ 20 μm in size.

chlorite :- anhedral plates ~ 20 μm in size.

muscovite/fuchsite:- anhedral grains 20 μm in size.

The unit is a medium silty shale. Spotting in the section is probably related to hornfelsing and the development of cordierite (which has long since retrogressed to chlorite and sericite).

Veins:-

Vein 1:- qtz-chl

Vein 2:- calcite-py vein

Interpretation:-

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Retrogression.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Quartz-chlorite-calcite-pyrite.

Name :- Hornfelsed shale; Quartz-chlorite vein; Calcite-pyrite vein.

BD056e
Batman Hill, DDH BD056 - 115.20 m.
Ref Nos:- B090
PTS

Macroscopic:- hornfelsed shale with pellett material and crosscut by veins.

Microscopic:- (on veins only)
Qtz-cal vein cuts qtz-chl vein and chl vein. Clearly, quartz-chlorite veins are cut by calcite-quartz veins which tend to run with the quartz-chlorite veins and thus masking the difference in the timing of their genesis, i.e., qtz-chl vein=> qtz-cal vein & chl vein = > qtz-cal vein.

Interpretation:-
1. Quartz-chlorite vein.
2. Quartz-calcite vein & chlorite vein.
3. Qtz-calcite.

Name:- hornfelsed shale, qtz-chl vein, chl vein, qtz-cal vein.

BD057a
Batman Hill, DDH BD057 -120.46 m.
Ref Nos:- B071
PTS

Macroscopic:- sediment cut by veins.

Microscopic:-
wallrock:- Area 1:- quartz clasts in a matrix of quartz, chlorite, sericite, and accessory minerals (N.B. the apparent hematite in this section is the result of grains emplaced during section preparation, i.e., it is carborundum). Clusters of sericite and chlorite are suggestive of psuedomorphs after feldspar, shale and other rock fragments, and chert clasts are also evident. (=> sandy shale).
Area 2:- is a spotted quartz-chlorite matrix which suggest that the unit has been hornfelsed, i.e., as evident from other sections, spotting is associated with the development of cordierite spots but is commonly only seen in the retrogressed form as sericite and chlorite. These define two fabrics. The spots are elongate parallel to the stronger fabric.
Area 3:- Fragmented sandy shale (as for Area 1) which is cemented by clean calcite. Clasts are surrounded by a rim of euhedral chlorite and occasional euhedral calcite crystals. Further spaces are filled entirely by clear euhedral calcite.
veins:- all the veins are late and postdate S2 because they truncate the S2 fabric.
Vein 1:- quartz-chlorite vein.
Vein 2:- quartz-chlorite-chalcopyrite.
Vein 3:- chlorite-calcite => calcite rind to clasts in Area 3.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Deformation with retrogression.
5. Fracturing.
6. Quartz-chlorite vein.
7. Fracturing.
8. Quartz-chlorite-chalcopyrite vein.
9. Fracturing.
10. Chlorite-calcite ----> calcite.

Name:- hornfelsed sandy shale, qtz-chl vein, qtz-chl-ccp vein, chl-calcite vein.

BD060a
Batman Hill, DDH BD060 - 2.6 m.
Ref Nos:- B072
PTS

Macroscopic:- chlorite aggregate.

Microscopic:-
The minerals are predominantly an aggregate of chlorite which has been stained by Fe-oxides. One or two zircons are present (~ 10 μm in size).

Name:- chlorite aggregate.

BD074a
Batman Hill, DDH BD074 - 60.0 m.
Ref Nos:- B079.
PTS

Macroscopic:- shale unit.

Microscopic:- the section is entirely that of a sedimentary unit which has been hornfelsed. Quartz clast are ~ 200 μm in size, are anhedral and angular to rounded. Mono- and poly-crystalline clast are evident. Matrix material is composed of quartz, sericite and chlorite ~ 15 μm in size, i.e., => sandy fine silt mud or sandy shale.
An aggregate of colloidal pyrite is late. It is not clear of its relationship since it is damaged by polishing.
N.B. hematite in the section is LAPCRAPITE (section polish).

Interpretation:-
1. Sedimentation.
2. Hornfelsing?

Name:- hornfelsed sandy shale.

BD075a
Batman Hill, DDH BD075 - 67.95 m.
Ref Nos:- B080.
PTS

Macroscopic:- sediment with disseminated pyrite and crosscut by two fine vein types.

Microscopic:-
wallrock:-
Area 1:-
quartz:- (50%), 50 μm in size, angular to rounded clasts.
chlorite 1:- (50%), 20 μm in size, anhedral to euhedral grains with a string green colour. Brown coloration appears to relate to goethite from weathering.
chlorite 2:- large plates of chlorite which is a pale green. Is associated with pyrite aggregates.
marcasite:- aggregates of anhedral grains and has some association with chlorite 2.
chlorite-sericite aggregate clots which define a fabric, are relic cordierite spots.
biotite:- dominant outside the clots but does occur throughout.
=> siltstone.

Area 2:-
quartz:- (80%), ~ 50 μm in size.
chlorite 1:- (20%), < 20 μm in size.
=> muddy sandstone.
Younging is indicated from micro-fining down-section. Spotting occurs in Area 1 (and is subtle in Area 2) and is indicative of hornfelsing.
veins:- vein 1:- quartz vein.
vein 2:- chlorite-marcasite vein.
i.e., quartz vein => chlorite-marcasite vein.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric.
4. Fracturing.
5. Quartz vein.
6. Fracturing.
7. Chlorite-marcasite vein.

Name:- Hornfelsed siltstone and muddy sandstone; Qtz vein; Chl-marcasite vein.

BD079b
Batman Hill, BD DDH079, 264.0m.
Ref Nos:- B092
PTS - Section is damaged.

Macroscopic:- quartz-pyrrhotite vein.

Microscopic:- (sulphides only description).
pyrrhotite:- major sulphide mineral. Subgrain development is indicative of recystallisation, probably due to post emplacement stress. The pyrrhotite is heavily fractured and a co-precipitate with iss (cubanite) and iss (talnakhite). Bismuth and gold grains, in intimate association, lie within fractures in the pyrrhotite.
arsenopyrite:- anhedral to subhedral grains which are fractured and infilled with pyrrhotite. Strongly idiomorphic after loellingite and may be a replacement of that mineral. The arsenopyrite is partly consumed by the pyrrhotite as indicated from the embayed form of the grain. Their anisotropy in crossed polars indicates they are zoned.
gold:- associated intimately with bismuthinite, bismuth and talnakhite. Gold is 799, 787, 999 (X2 grains), and 998 fine.
bismuthinite:- associated intimately with gold, bismuth and talnakhite.
bismuth:- associated intimately with bismuthinite, gold and talnakhite.
talnakhite:- associated intimately with bismuthinite, bismuth and gold. The mineral is sometimes found within pyrrhotite (along fractures) thus indicating that it postdates that sulphide.
chalcopyrite:- curved margins where in contact with pyrrhotite (=> coeval precipitation) but is also crosscutting. Chalcopyrite is thus syn- to post-pyrrhotite.
iss (cubanite):- curved margins where in contact with pyrrhotite (=> coeval precipitation). Also found as isolated grains in arsenopyrite.
sphalerite:- accessory mineral which contains tiny blebs (<1 μm) of chalcopyrite. It is pale orange colour would indicate it is low in Fe.

Interpretation:-
1. Pyrrhotite-iss (cubanite)- iss (talnakhite).
2. ?Loellingite - as indicated by idiomorphic arsenopyrite.
3. Pyrrhotite-chalcopyrite.
4. Chalcopyrite.
5. Arsenopyrite.
6. Au-bismuth-bismuthinite-talnakhite.

BD080q (1-3)
Batman Hill, DDH BD080, 100m.
Ref Nos:- B100
DPTS - Probe results available.

Macroscopic:- quartz-pyrrhotite vein.

Microscopic:-
wallrock:-

Area 1:- fine matrix of chlorite, sericite, hematite and quartz. No clasts exceed 10 μm thus making the sediment a fine grained muddy siltstone. Within the alteration zone, grains of gold and bismuth occur, and are < 1-2 μm in size. Sphalerite and chalcopyrite anhedra occur throughout. Chlorite and sericite define a strong fabric sub-perpendicular to the wallrock, and a weak fabric ~ 45° to the wallrock. (==> fine muddy siltstone).

Area 2:- consist of quartz clasts in a fine matrix of chlorite, sericite, hematite and quartz. The quartz clasts are 200 μm in size while the matrix is as for Area 2. Fabric orientations are weakly dined. (==> sandy fine muddy siltstone).

Vein:- crack-seal quartz lines the vein wall, is brecciated and contains sulphides of pyrrhotite, chalcopyrite, and sphalerite. Au and Bi grains (+bismuth sulpha-salts) occur throughout. Chlorite occurs as a gangue mineral. Trails of fine fluid inclusion lie parallel to the weak wallrock fabric.

pyrrhotite:- massive anhedral masses lie within fractures and clearly postdate the crack-seal quartz. Deformation or corrugation lamellae parallel the weak wallrock fabric and make the pyrrhotite variably anisotropic.

pyrite:- po ----> py + marcasite

marcasite:- po ----> py + marcasite

chalcopyrite:- contacts pyrrhotite and is probably a syn precipitate.

galena 1:- contains a trace of bismuth. Generally found and associated with bismuth, bismuth sulpho-salts, and Au.

galena 2:- Occurs within a bismuth grain. A high Bi bearing galena that is halfway between heyrovskyite ($Pb_{6-x}Bi_{2-x}S_9$) in composition.

bismuth:- commonly anhedral and associated with Au/Ag, bismuthinite, UN_{CuFeS}, Bi rich galena.

bismuthinite:- commonly anhedral. As an alteration of bismuth metal.

native gold:- commonly anhedral and 905, 926 and 833 fine.

hedleyite:- $Bi_{14}Te_6$ or Bi_5Te_3. Occur as rare anhedra.

UN_{CuFeS} :- as exsolution within pyrrhotite, but is consumed by pyrite and marcasite.

pavonite:- $Ag_{1.38}S.3Bi_{1.5}S_3$ Occurs as a rim to a native gold grain.

The galena 1 & 2, bismuth, bismuthinite, hedleyite, native gold, and pavonite occur in fractures throughout, and thus are late.

Interpretation:-
1. Sedimentation.
2. Deformation with retrogression - S1 fabric.
3. Fracturing.
4. Crack-seal veining.
5. Fracturing.
6. Pyrrhotite + chalcopyrite.
7. Chalcopyrite
8. Pyrrhotite --> pyrite + marcasite.
9. Fracturing.
10. Galena 1 & 2, bismuth, bismuthinite, hedleyite, native gold, talnakhite and pavonite.
11. Marcasite (sup)

Name:- Sandy fine muddy siltstone and fine muddy siltstone; qtz-po-ccp-py-mar-tal-bis-bismuthinite-hed-gold-pav-galena 1 & 2.

BD081a (1-2)
DDH BD081, 141.65-141.71 m.
Ref Nos: A151
PTS, DPTS

Macroscopic:- Calcite-sphalerite-galena vein in chloritised greywacke.

Microscopic:- Section is too thick for analysis of the sediment.
wallrock:- quartz grains (~ 300 μm) and chlorite/sericite => muddy sandstone.
veins:-

vein 1:- vein sulphides include chalcopyrite, galena, sphalerite, pyrrhotite all in calcite.
sphalerite:- (15%) anhedral masses; zoned (as defined by fluid inclusions and colour banding). Consumes chalcopyrite consuming pyrrhotite, and also consumes galena.
galena:- (5%) anhedral masses. Consumes pyrrhotite.
chalcopyrite:- (2%) anhedral masses; as rims to galena, along fractures through sphalerite, and consumes pyrrhotite.
pyrrhotite:- (tr) anhedral mass and is often surrounded by galena, and occasionally by chalcopyrite.
covellite:- (tr) late stage alteration mineral.
calcite:- (78%) comprises most of the vein; contains numerous fluid inclusions. It clearly precipitated after the other minerals and commonly terminate into vugs.

vein 2:- quartz, calcite and sphalerite with pyrrhotite, pyrite and marcasite. Pyrrhotite being consumed by pyrite being consumed by arsenopyrite.
vein 3:- chlorite vein cuts the wallrock and is cut by vein 1.
vein 4:- chlorite and quartz vein. Is cut by vein 1.
Relationships are poorly defined - NOT SUITABLE FOR PARAGENETIC WORK.

Interpretation:- sediment was fractured to allow veining, pyrrhotite, galena, sphalerite, chalcopyrite and calcite. Arsenopyrite is later and covellite is a late supergene mineral.

1. Sedimentation.
2. Fracturing
3. Po ---> gn ----> sp ----> ccp -----> calcite.
4. Fracturing.
5. Marcasite (supergene)

Name:- Po-gn-sp-ccp-cal vein, muddy sandstone.

BD087a (1-2)
DDH BD087, 267.78-297.94 m.
Ref Nos: A169
DPTS, PTS

Macroscopic:- a greywacke which is host to a pyrite-sphalerite-galena-calcite vein crosscutting a quartz vein.

Microscopic:-
wallrock:- sandy siltstone. Chlorite-sericite defines two fabric orientations, one weak, one strong. Spotting in the wallrock is probably after cordierite and is transgressed by the wallrock fabrics. The wallrock is heavily brecciated and it is not possible to establish if the fabrics transect the veins.

veins:-

vein 1:- poorly defined crack-seal quartz with fibres elongate perpendicular to the vein wall. The fibres are considerably fractured and are filled with calcite and sulphides. Sulphides include chalcopyrite, sphalerite, galena, marcasite and minor pyrrhotite.

chalcopyrite:- subhedral masses with smooth curved and embayed contact margins with galena and marcasite.

marcasite:- spongy and bookleaf masses which clearly consume galena and chalcopyrite. The marcasite contacts sphalerite roughly and the texture suggests marcasite postdates sphalerite.

pyrrhotite:- where it contacts marcasite and galena, it is embayed. It appear syn-formational with pyrrhotite.

galena:- appears to consume pyrrhotite and chalcopyrite.

vein 2:- These are calcite-sulphide veins which crosscut vein 1. Sulphides in the vein consist of marcasite consuming sphalerite consuming chalcopyrite and galena (as above).

vein 3:- chlorite vein:- This crosscuts vein 1. Chlorite fibres lie sub-perpendicular to the vein wall, and parallel the wallrock fabric. Either the fibres grew during fabric development or have grown syntaxial to the chlorite in the wall. Either way, the chlorite precedes galena, sphalerite and marcasite, i.e.,

vein 1 ---> vein 3 ---> vein 2

vein 4:- major calcite-sulphide vein which crosscut vein 1 - 3. Sequence of precipitation is recorded in the interpretation.

The calcites in this section all display undulose extinction and must therefore record some post emplacement deformation.

<u>Interpretation</u>:-

1. Sedimentation.
2. Hornfelsing - spots after cordierite.
3. Deformation and retrogression (S1).
4. Fracturing.
5. Crack-seal quartz.
6. Pyrrhotite + chalcopyrite.
7. Fracturing.
8. Chlorite veining.
9. Fracturing.
10. Vein sulphides and Cauliflower type 1 - (core) galena.
    sphalerite.
    chalcopyrite.
    sphalerite.
    sphalerite and galena intergrowth.
    calcite + sphalerite + chalcopyrite.
    pyrite euhedra.
11. Fracturing.
12. Cauliflower type 2 - (base layer 1) pyrite + galena + calcite.
    (base layer 2) pyrite + galena.
    (cauliflower) pyrite ==> pyrite + galena.
    pyrite coating over cauliflower.
    calcite layer.
    galena* + calcite.

    (Galena * is deformed and contains shears or kinks. The shears sub-parallel the weak wallrock fabric, which else where is S1. It lies approximately 45° to the strong fabric which elsewhere is S2. Sense of movement is sinistral. The fabric in the galena may relate to a $\sigma 1_{S2}$ directed from the north as for D2, suggesting that D2 postdates the emplacement of the galena.)
13. S2 fabric.
14. Marcasite (supergene).

<u>Name</u>:- Very fine sandstone with veins 1-4.

BD090d (1-2)
DDH BD090, 222.13-222.12 m.
Ref Nos: A159
DPTS, PTS

Macroscopic:- pyrrhotite-quartz vein.

Microscopic:- a sediment which has played host to a breccia style vein, which has again been brecciated.

sediment:- consists of quartz, sericite and chlorite. Chlorite clots may represent highly altered cordierite spots. The chlorite and the sericite define 2 fabrics. The chlorite clots are elongate in the direction of the fabric (following the logic, the cordierite spots would be pre-fabric in origin). S2 is weakly defined.

Opaques are scattered throughout the sediment and include pyrrhotite, chalcopyrite and ilmenite.

Pyrrhotite and chalcopyrite are associated with fractures and are not a primary sedimentary opaque.

veins:-

quartz:- (36%) the quartz is of the crack-seal type with tiny fluid inclusions orientated parallel to sub-parallel to the crystal length. The quartz crystal are not necessarily orientated perpendicular to the vein wall and often display ribbons of undulose extinction perpendicular to parallel to crystal length. This, together with the occurrence of granoblastic quartz, is suggestive of a late stress induced re-equilibration of crack-seal quartz.

pyrrhotite:- (10%) anhedral; occurs in fractures within the quartz and the sediment; spongy texture; intimately associated with chalcopyrite; probably precipitated together with quartz.

chalcopyrite:- (4%) anhedral; occurs in fractures within the sediment, pyrrhotite and quartz.

sphalerite:- (tr) possible co-precipitate of chalcopyrite.

arsenopyrite:- as accessory mineral in pyrrhotite.

calcite:- occurs in fractures throughout which crosscut the S2 fabric.

marcasite:- supergene alteration of sulphides.

Interpretation:- deposition of the sediment, brecciation, precipitation of quartz (crack-seal), brecciation, precipitation of quartz/pyrrhotite, brecciation, precipitation of chalcopyrite/chlorite/quartz (and sphalerite).

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Crack-seal quartz.
6. Fracturing.
7. Quartz-po-ccp-chl.
8. Arsenopyrite.
9. Brecciation.
10. Deformation and S2 fabric.
11. Calcite vein.
12. Marcasite (supergene).

Name:- Quartz-pyrrhotite vein; chalcopyrite-chlorite-sphalerite-quartz vein.

BS001
Tollis Formation - Batman South
Ref Nos: A38
PB

Macroscopic:- gossaneous material in quartz.

Microscopic:-
pyrite:- (1%) anhedral to euhedral crystals; up to 100 μm in size.
chalcopyrite:- (tr) anhedral to euhedral crystals; up to 10 μm in size.
covellite:- (tr) supergene alteration product of chalcopyrite.
gold:- (tr) 25 μm anhedral masses in goethite.
pyrrhotite:- (tr) 25 μm in size, anhedral, smooth curved margins with chalcopyrite which may imply co-precipitation or equilibrium between the phases.
goethite:- (20%) after hematite.
hematite:- (30%) fine grained coating in rims around and along fractures, type of reniform growth, vuggy in morphology and has acted as fill.
quartz:- (49%) major gangue mineral.

Interpretation:- The section consists of pyrite, chalcopyrite, pyrrhotite, gold, goethite, hematite and quartz. Pyrite, chalcopyrite and pyrrhotite occur as small inclusions within the quartz and possibly indicate a parent sulphide assemblage. Gold occurs as small inclusions in the quartz, but also in goethite or hematite. This may suggests that a post sulphide brecciation of the rock has occurred, the sulphides having been weathered leaving the gold behind. Hematite is not crystalline in its form, and is probably low temperature in origin, perhaps even epithermal. Goethite is a late alteration product of hematite. Covellite is a supergene alteration of chalcopyrite and pyrrhotite.

py & po/ccp => brecciation => hm => goet/cov
Au timing is not clear.

1. Po-py-ccp.
2. Fracturing.
3. Hematite.
4. Alteration - goethite & covellite.

Name:- gossaneous, gold bearing, quartz breccia.

BS002
Tollis Formation - Batman South
Ref Nos: A39
TS

Macroscopic:- hornfels

Microscopic:-
biotite:- (30%) euhedral plates up to 25 μm in size with an average grain size of 12.5 μm.
quartz:- (30%) up to 25 μm in size; is possibly polygonal.
opaques:- (2%) scattered throughout and up to 20 μm in size.
tourmaline:- (tr).
cordierite spots:- (38%) the spots have a central circular (spherical) core surrounded by a darker circular rim and a white rim, (200 μm in diameter).The latter has serrated edges. This rim gives the spots an elongate appearance, however, the elongation is not similar from one spot to another. Some elongation seems to coincide with an alignment of sericite and chlorite plates as might be seen if a fabric had developed. Cordierite spots measure up to 2 mm.
chlorite:- (tr)

Interpretation:- Clearly, the sample is of a hornfelsed siltstone. Two cordierite spots are present. One is grossly flattened, the flattening parallels a fabric defined by sericite and chlorite. The second is more ovoid and elongate with respect to the weak fabric. The angular difference in the elongation is 20° - 40°. Because of the numerous inclusions of biotite and quartz within the cordierite spots, it seems that cordierite growth has occurred somewhat after the development of biotite and the possible re-equilibration of quartz, such that the biotite and quartz have become trapped. The high proportion of biotite in regions outside of cordierite spots would suggest that biotite continued to develop along with the cordierite. That is, the sediment was subjected to high temperature which saw biotite develop and quartz re-equilibrate. With increasing temperature, biotite development was coeval with that of cordierite. The presence of chlorite may indicate metamorphic retrogression. The size of the cordierite spots is similar to that of cordierite spots as seen elsewhere and may suggest coeval development at those sites. If this is true, it associates this hornfels with H1 event. Opaques are clearly post hornfelsing given their general scattered occurrence, and their anhedral nature and may be related to pyritisation or hematisation during a later decrease in temperature. Tourmaline occurs throughout. Bedding is defined by compositional layering reflected by an increased percentage of biotite, relative to quartz, in individual layers.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite & ?biotite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Hornfels 2 - spots with cordierite, & biotite.
5. Deformation with retrogression - weak S2 fabric.

Name:- finely spotted, X2 deformed, X2 hornfelsed siltstone.

BS003a
Batman South
Ref Nos:- A040
TS

Macroscopic:- weathered porphyry dyke.

Microscopic:-
phenocrysts:-
S-spar:- multiply twinned, subhedral laths to 8 mm in length. Extinction Ab50An = andesine-labradorite. Alteration = deuteric and sericitic.
K-spar:- carlsbad twinned, subhedral laths to 1 cm in length. Glomeroporphyritic (PHOTOGRAPH) in part (= orthoclase), i.e., some large laths (10 X 0.5 cm) in clumps + some small laths (0.5 mm) in clumps (to 0.5 cm). The latter are anhedral. Alteration = deuteric and sericitic.
quartz:- anhedral and partially reabsorbed equant crysts to 1 mm in size.
zircons:- one euhedral lath to 200 μm.
groundmass:-
quartz:- (20%) anhedral polygonal equant crysts to 20 μm in size.
chlorite:- (10%) anhedral plates to 40 μm X 15 μm in size. Randomly distributed throughout the section and possibly after biotite since they have a major association with zircons and Ti relics.
S-spar:- (5%) minor constituent throughout the groundmass. Is anhedral and equant in from. Twinning only evident on rare crysts. 20 μm in size.
K-spar:- (60%) anhedral polygonal equant crysts to 20 μm in size. Carlsbad twining evident. (=> orthoclase)
zircons:- accessory
(==> porphyritic quartz microsyenite)

veins:- chlorite-goethite vein

chlorite:- platey to spherulitic masses to 1 mm in size. Strongly associated with goethite. Zircons and Ti relics suggest chlorite is after biotite.

goethite:- as an alteration throughout the section.

Interpretation:-

1. Intrusion of porphyritic quartz microsyenite.
2. Fracturing.
3. Veined by chlorite? & sulphides.
4. Weathered and goethitised.

Name:- weathered and mineralised porphyritic quartz microsyenite.

BS003c

Batman South

Ref Nos:- A040

PTS

Macroscopic:- porphyry dyke.

Microscopic:-

phenocrysts:-

S-spar:- multiply twinned, subhedral laths to 1.6 mm in length. Extinction Ab30An = andesine. Alteration = deuteric and sericitic.

K-spar:- carlsbad twinned, euhedral to anhedral laths to 1 cm in length (mostly 2 mm). Square, diamond and six sided crysts (= orthoclase). Alteration = deuteric and sericitic.

quartz:- anhedral and partially reabsorbed equant crysts to 1 mm in size.

groundmass:-

quartz:- (20%) anhedral polygonal equant crysts to 10 - 15 μm in size.

chlorite:- (10%) anhedral plates to 30 μm X 15 μm in size. Randomly distributed throughout the section and possibly after biotite since they have a major association with zircons and Ti relics.

S-spar:- (5%) minor constituent throughout the groundmass. Is anhedral and equant in from. Twinning only evident on rare crysts. 20 μm in size.

K-spar:- (60%) anhedral polygonal equant crysts to 20 μm in size. Carlsbad twining evident. (=> orthoclase)

zircons:- accessory

(==> porphyritic quartz microsyenite)

veins:- chlorite-pyrite-? vein

chlorite:- platey to spherulitic masses to 1 mm in size. Zircons and Ti relics suggest chlorite is after biotite.

pyrite:- associated with ?. Anhedral masses.

opaques:- (PROBE)

Interpretation:-

1. Intrusion of porphyritic quartz microsyenite.
2. Fractured. Veined by chlorite-pyrite-opaques.

Name:- mineralised porphyritic rhyolite.

C001a & C001b
Cullen Batholith - within the Tennysons leucogranite.
Ref Nos: A10
TS (X2)

Macroscopic:- Sericitised metagranite.

Microscopic:- Non holocrystalline metagranite composed of quartz, sericite, and muscovite.
quartz:- (50%) anhedral throughout; up to 5 mm in size; generally displays undulose extinction; some micro-ribbon texture development has seen the fragmentation of quartz to produce small crystals of anhedral quartz at sites where high stress has been applied.
muscovite:- (10%) generally 1.0 mm in size, random plates; the plates have irregular edges that give way to fine grained sericite; as with quartz, the muscovite plates contain high stress re-equilibration textures, i.e., micro-kink structures; the presence of titanium relics and the presence of euhedral to subhedral zircons (0.024 mm long) may suggest that muscovite developed from the alteration of biotite (N.B. there exists an association of zircon with biotite to produce uranium haloes in other granites of the Cullen Batholith).
sericite:- (40%) fine anhedral plates; possibly after feldspars; its occurrence at the margins of plates of muscovite suggest some of the sericite is a re-equilibration texture of muscovite.
zircons:- (tr) euhedral to subhedral zircons (0.024 mm long); generally associated with muscovite plates.
tourmaline:- (tr) euhedral grains growing as rays and clusters of ray-like crystals around muscovite/sericite plates, as well as within quartz crystals; individual tourmaline rays are up to 0.75 mm long. No one ray is continuous but is made up of segments of euhedral crystals.

Interpretation:- Clearly there has been re-equilibration and alteration of the original granite texture such that feldspars and biotite have completely re-equilibrated to muscovite. It is possible that the muscovite and tourmaline developed during greisenation of the granite. Most of the sericite seems to be related to late stage alteration of the muscovite. Two weak fabrics are evident. One which resolves fracture and shear features in muscovite, as well as re-equilibration of the same. The other crosscuts this and parallels the granoblastic features which crosscut crack-seal veins. Is also seen as strain features in muscovite.

1. Granite emplacement.
2. Greisenation.
3. Deformation - S1 fabric.
4. Crack-seal quartz.
5. Deformation - fractures of granoblastic quartz, muscovite strain features.

Name:- Sericitised, (possibly) hornfelsed, X2 deformed granite.

C002
Cullen Batholith - within the Tennysons leucogranite.
Ref Nos: A11
TS

Macroscopic:- granite

Microscopic:- holocrystalline and therefore igneous.
quartz:- (22%) 1 mm euhedral to subhedral crystals with slight sweep to undulose extinction suggesting some post emplacement strain; crystals are clear.
Microcline:- (40%) laths up to 2.5 mm in length displaying microcline cross hatched twinning; also as matrix grains measuring up to 1 mm; is dusted with fine sericite suggesting some post emplacement alteration; occasional deuteric alteration; some carlsbad twinning as well as microcline twinning.
plagioclase:- (20%) anhedral grains displaying multiple twinning; laths up to 1.75 mm in length with complex multiple twins; also as anhedral grains up to 0.75 mm in length in the matrix; large laths generally display fine sericitic alteration and is confined to the cores; the cores are surrounded by unsericitised plagioclase in optical continuity with the sericitised plagioclase; contact of K-spar and/or quartz with plagioclase shows ragged edges to plagioclase possible implying some re-equilibration.
biotite:- (15%) biotite occurs as background to K-spar/plagioclase/quartz and is pale brown pleochroic; some chloritisation has left titanium relics; zircons are common in the biotite and are denoted by uranium haloes.
zircons:- (1%) up to 1.0 mm in length; high relief and high birefringence; generally associated with biotite but occasionally as free euhedral grains of 0.06 mm lengths.
sericite:- (2%) after feldspar: small blades generally aligned to xtal cleavage planes in K-spar.
chlorite:- (tr) alteration of biotite.
rutile:- (tr) > 0.01 mm elongate euhedral grains generally in the biotite.
apatite:- (tr).

Interpretation:-
1. Emplacement of the granite.
2. Chloritisation of biotite, sericitisation of feldspar.

Name:- microcline-plagioclase-quartz-biotite leucogranite (adamellite) N.B. it lies close to adamellite field on the Streckeisen diagram.

C003
Cullen Batholith - within the Tennysons leucogranite.
Ref Nos: A12
TS

Macroscopic:- metamorphosed porphyritic alkali feldspar granite.

Microscopic:- Not holocrystalline any more;
microcline:- (40%) classically cross hatched or tartan twinning. In sites of higher stress, it is altered to chlorite and sericite/muscovite. It is affected by late stage Fe-oxide alteration; microcline occurs as large fractured and ribboned laths which are phenocrysts in hand specimen. The microcline phenocrysts commonly display an agglutination texture. Microcline in the matrix occurs with quartz.
quartz:- (40%) anhedral grains, the margins of which show recrystallisation in the manner of metamorphism, i.e. re-equilibration of the margins of the quartz to produce fine quartz crystals. Metamorphism is further supported by the occurrence of sweeping undulose extinction and the development of micro ribbon quartz development.
chlorite, sericite, Fe-oxides:- (20%) forms the rest of the bulk rock; aggregates of these three in elongate hexagonal lath shapes may be indicative of pseudomorphs of hornblende? Possibly some of this is alteration after biotite, given the presence of titanium relics associated with some of the sericite and chlorite.

Interpretation:- There is no evidence of plagioclase. It is clear that the granite has been considerably stressed after its emplacement. High stress sites in quartz have seen the development of micro ribbon texture with the development of fine (0.5 μm) anhedral crystals of quartz (these define the ribbons per say). High stress sites in feldspars have seen the development of similar micro ribbon texture, with sericite and quartz defining the ribbons. The occurrence of chlorite appears to be late, although it may have resulted from the decomposition of biotite during metamorphism. An obvious fabric has been developed. Although granitic in nature, the granite is no longer holocrystalline and must be considered metamorphic.

1. Emplacement of leucogranite.
2. Deformation (*?).

Name:- metamorphosed porphyritic K-feldspar leucogranite

C004
Cullen Batholith
Ref Nos: A13
TS

Macroscopic:- Hornfels raft in C003

Microscopic:-
quartz:- (65%) up to 2 mm long angular clasts in a matrix of angular to subrounded quartz, muscovite, biotite and opaques. In the matrix, quartz is polygonal in shape where quartz contacts quartz. Using large clast orientation, it is possible to determine a weak relic bedding orientation. Regrowth of the quartz is evident from the numerous trapped inclusions lying in zones that denote the margins of the parent quartz grains. Strain features are not seen within the quartz suggesting an increase in temperature without the influence of significant pressure, i.e., conditions as for contact metamorphism.
muscovite:- (30%) developing as background plates to quartz clasts and perhaps recrystallising from relic sericite flakes.
biotite:- (3%) forming as a background to quartz clasts.
zircons:- (tr)
opaques:- (2%) found throughout.

Interpretation:- There has been re-equilibration of the original texture such that quartz and sericite have grown to produce quartz and muscovite. This has occurred without significant stress but in an environment of increasing temperature, i.e., conditions of contact metamorphism.

1. Sedimentation.
2. Hornfelsing.
3. Deformation (*?)

Name:- hornfelsed sandy siltstone.

C007 (1-3)
Cullen Batholith
Ref Nos: A16
TS

Macroscopic:- a bedded hornfelsed silty greywacke

Microscopic:-
wallrock:-
Area 1 - a silty/sandy bed in the hornfels:-
quartz:- 50%; mostly anhedral; 125 μm in size.
chlorite:- 15%
muscovite:- 25%; 100 μm in size.
biotite:- 5%; 50 μm in size.
opaques:- 2%; scattered throughout; 10 μm.
zircons:- accessory.
Bedding can be determined by clast length orientation, and is in reality, a compositional layering.
Area 2 - a siltstone/shale bed in the hornfels:-
quartz:- 40%; 25 μm in size.
chlorite :- 3%; lies in bedding parallel elongate clots as well as generally throughout the bed; 200 - 400 μm.
muscovite:- 40%; 50 μm plates.
biotite:- 5%; 30 μm.
opaques:- 2%; scattered throughout the bed; 10 μm.

Interpretation:- Clearly the two sedimentary types indicate a lithological change from a coarse silt to a fine silt. There has been some re-equilibration of plate-like grains, and the biotite appears to be secondary. Indeed, its random fine habit is suggestive of biotite grade contact metamorphism. Chlorites in the clots define a fabric which crosscuts bedding. The clots are most likely relic cordierite spots which have been chloritised. Biotite is not associated with the hornfelsing which produced those cordierite spots since it is found within the clots and out of the clots. The chlorite can not have formed during a retrogressive phase of a single contact metamorphic event else the biotite would have retrogressed also. Possibly conditions were sufficient for biotite to form, but insufficient for chlorite to fully react out but this would imply that biotite postdates chlorite. Perhaps a first hornfelsing event produced cordierite spots which retrogressed to chlorite. The second event re-hornfelsed the sedimentary pile, but in this case, only biotite was developed, i.e. no cordierite spots were developed. Two weak fabrics are developed. Both are defined by the orientation of platey mineral and the flattening of cordierite clasts. The sericite laths which define the first fabric are cut by the laths of the second. Biotite laths have a predominant orientation parallel to the weak fabric and probably precede it.

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Hornfels 2 - development of biotite.
5. Deformation - S2 fabric.

Name:- X2? hornfelsed, X2 deformed, siltstone and fine sandstone.

C008a
Yenberrie leucogranite
Ref Nos:- A017
TS

Macroscopic:- medium to coarse gained, quartz-mica leucogranite.

Microscopic:-
quartz:- (65%), 0.8 mm in size, subhedral to serrated in morphology, displaying undulose extinction and some sub-grain development.
muscovite:- (30%) becoming chloritised and alteration after biotite, i.e., there is evidence of re-equilbration. Chlorite contains titanium blobs indicating that the chlorite is also after biotite.
opaques:- (2%), associated mostly with muscovite although not exclusively.
goethite:- (3%) alteration feature.

Interpretation:- Numerous crosscutting fluid inclusion are evident in the section and the nature and morphology of the quartz is suggestive of post-emplacement stress. Together with the field data which records that the granite has a clear identifiable fabric, it is likely that the granite is pre-deformational in terms of its history, i.e.,

1. Emplacement of the leucogranite (biotite) &/or greisenation (muscovite).
2. Deformation (retrogression of micas to chlorite and titanium relics).
3. Alteration and the development of goethite.

Name:- deformed, greisenated, two mica leucogranite.

C008b (1-2)
Cullen Batholith
Ref Nos: A18
QP, DPTS

Macroscopic:- a veined granite greisen.

Microscopic:-
greisen:-
biotite:- (50%) coarse plates of biotite, 1 to 2 mm in size, slightly chloritised.
quartz:- (50%) up to 200 μm in size, polygonal, clear.
vein quartz:- (50%) occurs as large anhedral laths measuring up to 1 cm in size. The laths are crisscrossed by numerous secondary fluid inclusions which may or may not be useful for study.

Interpretation:- intrusion of a highly fractionated granite which has been greisenated. The greisen has been fractured and substantially veined.

Name:- a veined greisenated leucogranite.

C009a
Alfred - Yenberrie leucogranite
Ref Nos:- A019
DPTS

Macroscopic:- quartz from veins cutting the Yenberrie leucogranite.

Microscopic:-
quartz:- anhedral crysts > 5 cm in length (full section width). The is no apparent zonation of quartz but the quartz is full of 2° fluid inclusions: LVV, V only, LV. Not really possible to establish a sequence of cross cutting trails. (=> buck quartz)
chlorite:- in a fracture in the quartz. Is spherulitic (CHLORITE ANALYSIS).
pyrite:- scattered throughout and mostly anhedral. Some euhedra are 15 μm in size and associated with chlorite.

Interpretation:-
1. Buck quartz.
2. Crosscut by chlorite-pyrite vein.

Name:- Buck quartz; chlorite-pyrite vein.

C009b
Vein in Alfred area.
Ref Nos:- A019
PTS

Macroscopic:- quartz-fluorite vein from within the Yenberrie leucogranite.

Microscopic:- is composition of quartz fluorite and Sn.
quartz:- (50%) the quartz is mostly clear, anhedral to subhedral, and of two sizes. The first are small equant subhedral grains to 350 μm of somewhat higher relief than the second. The second form anhedral plates of low relief and measure up to 1 mm in size. The second appear to be a recrystallised form of the first.
adularia:- (35%) subhedral rhombs to 500 μm in size. Becke line test indicates movement into the quartz. The shape and habit confirm adularia diagnosis. The shape suggests growth into open spaces. The adularia occurs in clusters and also in occasional euhedra of K-spar (orthoclase). It may have formed from decomposition of the K-spar.
muscovite:- (5%) as spherulitic plates and masses in fractures in the quartz-K-spar mass. The fractures follow grain boundaries but occasionally crosscut indicating there late history. They may define a spaced cleavage as such. The mineral is associated with fluorite and adularia.
fluorite:- (10%) as large masses of euhedral to subhedral crystals to 30 μm in size. The masses contain zircons associated with Ur haloes and suggest they are psuedomorphs of biotite.
zircons:- accessory.
what looks like tin:- LAPCRAPITE (section polish).

Interpretation:-
1. Emplacement of the leucogranite.
2. Fracturing and greisenation.
3. Replacement of biotite by fluorite, orthoclase by adularia, and feldspars by muscovite.

Name:- Greisenated leucogranite containing fluorite, adularia and muscovite.

C011
Cullen Batholith
Ref Nos: A26
TS
Macroscopic:- a fine grained intrusive (possibly dolerite dyke).

Microscopic:-
xenocrysts:- (20%)
S-spar:- < 3 mm, central core is surrounded by a sericitised rim which itself is being consumed at its margins. Ab30An = andesine.
calcite/chl/quartz:- the calcite and chlorite grains have ragged edges. Chlorite is partly spherulitic suggesting open space fill. Possibly the chlorite and calcite occupy amygdules or spaces which once contained xenocrysts.
matrix:-
opaques:- (5%) probably magnetite, as anhedral masses and plates (<0.05 mm in size). The unit is quite strongly magnetic.
biotite:- (35%) green brown pleochroic and mostly altered to chlorite. Titanium relics are present where biotite has been heavily altered to chlorite.
S-spar:- (25%) as laths up to 1 mm long.
quartz:- (10%) up to 0.2 mm in size. Contains numerous inclusions of apatite.
sericite:- (5%) alteration after feldspar.

Interpretation:- From the hand specimen xenocrysts are clearly evident, and microscopically the xenocrysts exhibit re-absorption features. The unit has behaved intrusively. The calcite/quartz/chlorite are suggestive of open space fill into a roughly circular cavity. Perhaps these spaces once contained olivine which was either replaced or weathered. Perhaps the space was an amygdule or a now long gone xenocryst? Certainly, the intrusive is quite chloritised to the point only a small amount of fresh biotite remains. The quartz is clearly magmatic, given the numerous apatite inclusions. The amount of quartz in the matrix makes it difficult to call this intrusive a dolerite, even if some of the quartz is secondary in origin (xenocrystic or inherited). Using a Streckeisen diagram (Ehlers and Blatt, p 105, 1976), it could be called a syenitoid. If most of the quartz is demonstrated to be secondary, then it is likely that the intrusive was an olivine basalt to fine dolerite.

1. Emplacement of dyke.
2. Alteration - chloritisation.

Name:- An olivine basalt or dolerite that has intruded a felsic intrusive and from which it has inherited numerous xenocrysts of feldspar, as well as some quartz. The intrusive has been heavily chloritised.

C013a
Cullen Batholith
Ref Nos: A28
QP, DPTS

Macroscopic:- quartz vein.

Microscopic:- the quartz vein is hosted in C003 which has been substantially silicified and chloritised. Feldspars have been completely altered to chlorite, micas have been recrystallised and coarsened during greisenisation, and the quartz of C003 is crisscrossed by fractures (as defined by fluid inclusion trails). The sample has been goethitised.
The vein itself consists of euhedral quartz crystals to 2 cm in length (from hand specimen), although some crack-seal veining, adjacent to the vein walls, suggest that crack-seal veining gave way to open space crystal growth. Fluid inclusions are all secondary and generally lie along fractures which cut the quartz crystals. They may or may not be useful for a fluid inclusion study.

Interpretation:- veined C003.
1. Sedimentation.
2. Fracturing.
3. Crack-seal quartz.
4. Fracturing.
5. Quartz vein.

Name:- quartz vein in C003.

C015
Cullen Batholith
Ref Nos: A51
TS

Macroscopic:- Granite intrusive into hornfelsed siltstone containing a concretion.

Microscopic:-
intrusive:- mineralogy consists of:-

S-spar:- (20%) multiple twinning with 20° extinction angle (= oligioclase to andesine); generally anhedral and 200 to 300 μm in size; multiple and carlsbad twinning evident.

K-spar:- (20%) carlsbad and weak tartan twinning (? = microcline); generally anhedral and occurs as groundmass to the other crystals.

quartz:- (40%) anhedral grains to 1 mm in size; contains numerous fluid inclusion trails which would suggest that fracturing has been a part of the post emplacement history of the intrusive.

biotite:- (5%) anhedral laths up to 1 mm long which are scattered throughout. They are heavily chloritised.

muscovite:- (3%) anhedral plates up to 2 mm long and scattered throughout the groundmass. Muscovite also occurs as rare anhedral to subhedral plates.

opaques:- (1%) mainly late Fe-oxide staining, probably consequent of weathering.

sericite:- (2%) 40-60 μm plates which occur as alteration to feldspar.

chlorite:- (acc) as alteration product of biotite.

The intrusive is a highly fractionated two mica granite greisen. The mine grid location of the sample suggest it is part of the Yenberrie Granite.

Hornfels:- mineralogy consists of angular quartz clasts (150 μm in size) in a matrix of polygonal quartz and subhedral biotite (50 μm).
quartz (10%)
biotite (45%)
quartz matrix (45%)

The original sediment could probably be described as a muddy coarse siltstone to muddy fine sandstone. It contains an ovoid structure (5 cm long X 3 cm wide) which has a distinctive core and rim structure.

rim:- consists of:-

(1) fine quartz-sericite rim in which grains do not exceed 25 μm. Opaques (up to 50 μm in size, 2% of the rim total) are scattered throughout. Quartz to sericite ratio is 50:50.

(2) quartz clasts (100 μm) set in type (1) rim material. Quartz to sericite ratio is 25:75. Opaques are more common than before (5%).

(3) quartz clasts (100 μm in size, 3% of the rim total) in a biotite - sericite - quartz matrix. The biotite occurs as background crystals to the matrix and is secondary in nature. opaques are strongly associated with the biotite (8%).

(4) as for (2).

core:- consists of:-

biotite:- up to 1.5 mm in size and forms 75% of the core mineralogy; commonly contains zircons with Ur haloes and is chloritised; strongly associated with opaques.

quartz:- rounded to subrounded grains that contain numerous apatite, tourmaline and other inclusions.

various clots:- within the core matrix are clots (clasts?) of polygonal and non-polygonal quartz, quartz-sericite, and sericite - quartz.

Interpretation:- The core of the ovoid structure indicates a mixed provenance, i.e., the clots are suggestive of an aggregate of sedimentary bits and pieces. The considerable amount of biotite in the cementing matrix of the core, may be a consequence of recrystallisation of mud. Possibly, the core was a ball of sedimentary material that was glued together, by mud, into a pellet. As an extension to this idea, the rims may have become cemented onto the core as the pellet rolled around. It is possible to imagine such a marine environment in which the major sediment type is a silt, but which is gentle enough to encourage pellets to roll around thereby accumulating sedimentary material. The whole sedimentary pile has been intruded by a highly fractionated two mica granite. The heat from the intrusion may have hornfelsed the sedimentary pile to hornblende-hornfels facies. The granite shows evidence of greisenation.

Name:- Intrusion of a highly fractionated granite into a coarse siltstone containing pellets. The sediment is hornfelsed and the granite is greisenated.

CHL001
Quigleys South pit
Ref Nos:- B151
PTS

Macroscopic:- Chloritised sandstone greywacke from the hanging wall adjacent to the lode.

Microscopic:-

wallrock:- Mainly quartz. Quartz occurs as elongate clasts up to 100 X 190 μm in size (the elongation defines two fabrics) which are supported by a matrix of sericite and chlorite. Matrix clasts of quartz measure ~ 25 X 20 μm. Their elongation defines two fabrics. Chlorite and sericite wrap around the elongate quartz clasts and matrix quartz, thus defining two clear fabric directions. These strike some 57 ° apart on the section (the section is not orientated.) Some mica fish are developed and shearing is evident. One fabric orientation is sheared and drag folded by the other. The age of the fabrics is not clear. Hematite masses are general throughout and measure 40 X 25 μm. They are late and may result from alteration of sulphides.

vein:- consists of anhedral crack-seal quartz fibres lying perpendicular to sub-perpendicular to the vein wall. Subgrain development, gross undulose extinction features, crosscutting fractures, shattered and twisted quartz grains all indicate that shearing was probably a post vein emplacement feature. Indeed, in part, the vein looks folded (=> post crack-seal shearing and folding).

Interpretation:-
1. Sedimentation.
2. Crack-seal vein. Fabric 1?
3. Fabric 2 - shearing, folding, microfaulting of the crack-seal vein.
4. Alteration and hematisation.

Name:- Sheared sandy siltstone; X2 fabric; fabric shearing crack-seal veins.

CHL002
Quigleys 10500 pit
Ref Nos:- B151
PTS

Macroscopic:- chloritised sandstone greywacke from the hanging wall adjacent to the lode.

Microscopic:-
wallrock:-
quartz clasts:- up to 500 X 320 μm in size. Elongation is randomly orientated.
lithic clasts:- as for quartz and consist of quartzites, chert and sericitised clast (feldspar?).
zircons:- accessory.
matrix:- chlorite, sericite and quartz. Quartz clasts are no greater than 25 X 25 μm,i.e, siltstone. Some alignment of chlorite and sericite to produce a fabric which crosscuts and offsets the vein material - shear fabric.
hematite:- as an alteration. Clots to 200 μm in diameter. Scattered throughout the wallrock.
Vein:- vein 1:- crack-seal quartz vein. Contains tiny (> 5 μm) pyrite euhedra adjacent to fractures (? 2°)
vein 2:- in reality these veins are microfractures in which all clast sizes have been reduced to polygonal sub-grains of quartz (10 μm). The microfaults cut vein 1 and the weak fabric is associated with the pyrite euhedra in vein 1.

Interpretation:-
1. Sedimentation.
2. Crack-seal quartz. Fabric?
3. Microfaulting and pyritisation.
4. Alteration and hematisation.

Name:- sandy lithic siltstone; crack-seal quartz vein; microfaulting and pyritisation.

CHL003
Quigleys 10500 pit
Ref Nos:- B152
PTS

Macroscopic:- faulted, veined and chloritised sandstone greywacke adjacent to the lode.

Microscopic:-
wallrock:- consists predominately of chlorite/sericite and some quartz. The quartz clasts are elongate and rarely exceed 20 X 20 μm in size. The chlorite and sericite describe a strong fabric. There is some compositional layering in the section, i.e., the alternation of quartz dominant layers and sericite/chlorite dominant layers. The fabric is sub-parallel to bedding. Spotting of two types is also evident:-
1. Quartz dominant spots measuring ~ 500 X 300 μm in size. They are elongate parallel to the wallrock fabric and are crosscut by this fabric, as indicated by minor chlorite and sericite.
2. Hematite/goethite dominant spots measuring 350 X 300 μm in size. The central portion of the spots is goethite or absent and may well have been sulphide at some stage, the spots thus resulting from the weathering of sulphide minerals. There is no chlorite or sericite and it is not clear if the spots are secondary in nature. Hematite masses (40 X 40 μm) are present throughout the wallrock, and in the two spot types.

vein:- vein 1:- quartz crack-seal veins. Crosscut by a strong fabric and some subgrain development is evident. Also microfractured with subgrains. Is bedding parallel and cuts type 1 spots.
vein 2:- microfaulted and goethitised/hematised vein. It crosscuts vein 1 and parallels the fabric. Where it parallels the fabric, is is seen to act as a microfault.

Interpretation:-
1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Fracturing.
5. Crack-seal quartz.
6. Veining, fracturing and microfaulting. ?Pyritisation of spots and the wallrock.
7. Weathering and goethitisation.

Name:- hornfelsed laminated fine siltstone; S1 fabric; crack-seal veins; microfaulting.

DC001
Tollis Formation - Delta Charlie.
Ref Nos: A33
DPTS

Macroscopic:- epithermal quartz.

Microscopic:- totally quartz, although some pink coloration is due to the presence of Fe-oxides. The quartz occurs as clear fluid inclusion free crystals orientated perpendicular to some defined base. It is clear that the crystals grew onto and away from this base into open cavities. Bases are parallel, much like a stack of plates, and crystals point inward from the bases. It is likely, as described elsewhere, that the quartz grew onto and replaced, plates of epithermal calcite, i.e., the calcite merely acted as a substrate.
The base-crystal structure is fractured.
Onto the fracture walls, acicular crystals of Fe-oxide have been deposited. These where probably hematitic in nature (as for JG002).
Clear fluid inclusion free quartz has been precipitated as fill over the Fe-oxides and often forms a star array around a core of quartz/Fe-oxide.
There are no usable fluid inclusions.

Interpretation:- substrate precipitation, quartz replacement of the substrate with precipitation of dogs tooth fluid inclusion free crystals into open cavities, fracturing, precipitation of Fe-oxides, precipitation of quartz.

1. Substrate precipitation.
2. Quartz replacement of substrate.
3. Precipitation of dog tooth quartz.
4. Fracturing.
5. Precipitation of Fe-oxides.
6. Precipitation of quartz.

Name:- epithermal quartz.

G001
Golf pit
Ref Nos:- A003
PTS

Macroscopic:- quartz hematite vein material.

Microscopic:-
quartz:- qtz 1 - (buck quartz) fractured anhedral quartz up to 5 mm in size. Subgrain development associated with fractures. Some elongation of the anhedral quartz may be consequent of crack-seal growth as indicated from parallel fluid inclusion trails perpendicular to the section length of the mineral. The quartz is also characterised by the numerous CO_2 fluid inclusions. The quartz displays undulose extinction.
qtz 2 - clear anhedral fractured quartz with fluid inclusions.
qtz 3 - clear (X2) quartz euhedra with growth zones that include goethite layers. No undulose extinction or fluid inclusions > 1 μm evident. Some evidence for qtz 3 overgrowing hematite overgrowing quartz 2 overgrowing hematite overgrowing quartz 1. Crystal terminations indicate that quartz grew as open space fill. (=> epithermal quartz)
hematite:- as goethite. Is a cover to buck quartz and a fill.

Interpretation:-
1. Buck quartz 1.
2. Fracturing. Sulphide?
3. Quartz 2.
4. Fracturing. Sulphides?
5. Epithermal quartz.
6. Goethitisation.

Name:- Buck quartz; hematite; epithermal quartz; hematite; epithermal quartz; goethitisation.

GN002
Tollis Formation - Golf North
Ref Nos: A20
TS

Macroscopic:- hornfelsed greywacke.

Microscopic:- quartz/sericite replacement of fine grained laminated shale. The greywacke has been hornfelsed to produce cordierite spots up to 0.8 mm in diameter. A fabric is developed at 64°-24° to bedding and is defined by alignment of tiny sericite plates. Cordierite spots are elongate in the direction of a fabric which must be interpreted as cleavage. There are two types of cordierite spots with the larger measuring 0.8 mm in diameter. The shape of the larger spots shows some flattening perpendicular to the above cleavage, and fracture shadows can be seen lying on either side of the spots. Tiny polygonal cordierite grains are evident with these larger spots. The smaller spots measure 0.2 mm in diameter and have completely retrogressed to an aggregate of sericite and chlorite with a halo of Fe-oxide. Sericite alignment parallel to the cleavage indicates these spots developed prior to the development of the fabric. Both hornfels spots and the fabric, are cut by a bedding parallel quartz vein.

Interpretation:- sediment deposition was followed by hornfelsing to hornblende-hornfels facies. Cordierite has developed in preference to andalusite and may reflect a low Al content of the sediment. Retrogressive metamorphism, which has seen sericitisation and chloritisation of the hornfels, was followed by some fabric forming deformation. A second hornfelsing event occurred synchronous to, or post, fabric development. Extension perpendicular to bedding produced strain shadows around the second spots, and may be indicative of a second deforming event. Bedding parallel fractures possibly developed during or after the second deformation. The late fractures are filled in with dog tooth quartz which is suggestive of open space fill.

1. Sedimentation.
2. Hornfels 1 - spots after cordierite. Also biotite.
3. Deformation with retrogression - S1 fabric and spot elongation.
4. Hornfels 2 - spots after cordierite. Also biotite.
5. Deformation with retrogression - S2 fabric and spot elongation.
6. Fracturing.
7. Quartz vein.
8. Fracturing.
9. Dog tooth quartz.

Implications:-
1. Two hornfelsing events
    (i) early event to produce small spots
    (ii) late event to produce large spots
2. Two deforming events
    (i) one event post early hornfels
    (ii) one event post late hornfels

More than one hornfels event has occurred in the region of Mount Todd but it is not clear which is responsible for the mineralising event, if any. Clearly, a fabric intersecting the veins at Batman to Quigleys, has developed during deformation. The fabric appears to parallel S2 and would thus suggest the veins are pre-S2. If this is true, which of the above deformations is S2 and how do the hornfelsing event relate to S2?

Name:- X2 hornfelsed, laminated shale with X2 fold history.

GN003
Golf North
Ref Nos: A035
PTS

Macroscopic:- Laminated shale.

Microscopic:-
wallrock:- composed of sericite and chlorite in equal percentages, and quartz. The sericite and chlorite define a cleavage which has been measured in the field as the S1 cleavage. There is some squashing of the quartz grains, and the long axis also defines the S1 cleavage. (The sericite and chlorite also define two subtle trends. One is bedding parallel and the other may be S2). Grains are generally 15 μm thus defining the sediment as a shale. It is laminated. Some goethite is present and hematite clots (<15 μm) are present throughout the section. Most goethite occurs in ellipsoidal masses (250 μm X 150 μm) which are suggestive of cordierite psuedomorphs. The masses are elongate in the S1 direction indicating that there origin must have been pre-S1. The S1 fabric clearly transgresses the masses. The sediment is goethitised.
vein:- quartz-chlorite vein but is strongly altered and goethitised.

Interpretation:-
1. Sedimentation.
2. Hornfelsing and cordierite.
3. S1 fabric development and re-equilibration.
4. S2 fabric development and re-equilibration.
5. Goethitisation.

Name:- hornfelsed , X2 deformed laminated shale.

GN004
Golf North
Ref Nos: A036
PTS

Macroscopic:- fractured laminated shale.

Microscopic:-
wallrock:- individual beds are defined by Fe-oxide staining, and by minor compositional differences. Generally, however, grain size is 25 μm and thus the unit is a shale. It is laminated.
The section is composed predominantly of quartz and sericite, however, at least 50% is goethite. (=> weathered laminated shale).
vein:- vein 1 - clear anhedral quartz that contains few fluid inclusions. The quartz is brecciated and there is some evidence to suggest quartz 1 overgrowth by hematite overgrowth by quartz 2 and finally infilled by hematite.
vein 2 - consists entirely of quartz which is clear and euhedral. Euhedra are 50 μm in size and at least one contains a vapour rich 1° fluid inclusion (10 μm). Hematite occurs as fill to everything. There is some pyrite associated with this quartz, the grains are anhedral and > 5 μm.

Interpretation:-
1. Sedimentation.
2. Fracturing & quartz 1 (brecciated).
3. Hematite (sulphides?) & quartz 2 (euhedral).
4. Geothitisation.

Name:- weathered laminated shale; quartz vein.

J001
Jones Brothers Workings
Ref Nos:- A029
PTS

Macroscopic:- siltstone.

Microscopic:-
quartz:- (50%) clear anhedral flattened grains measuring < 150 μm X 50 μm. The length of the clasts defines a fabric.
chlorite/sericite:- (50%) equant (~ 125 μm in diameter) and elongate (175 μm X 25 μm) patches of anhedral plates. These define two distinct cleavage orientation. The latter defines a cleavage.
zircons:- equant high relief rounded clasts measuring 15 μm in diameter. Generally associated with chlorite/sericite patches.
goethite:- tiny plates (<1 μm) scattered throughout. Indicative of weathering.

Interpretation:-
1. Sedimentation.
2. Deformation with retrogression - S1 fabric and spot elongation.
3. Deformation with retrogression - S2 fabric and spot elongation.
4. Alteration and weathering.

Name:- X2 deformed, weathered very fine sandstone.

J002
Jones Brothers Workings
Ref Nos: A66
PTS

Macroscopic:- epithermal quartz.

Microscopic:-
quartz:- (96%) zoned quartz where zones are defined by fluid inclusions. This quartz is fractured, the fractures containing chalcopyrite, pyrrhotite and chalcocite. All of this is brecciated, and each brecciated quartz piece is coated with tiny crystals of hematite. The hematite often forms a pomp-pomp texture. Following the hematite, clear quartz, free of fluid inclusions, has been precipitated. A second hematite stained quartz zone, free of fluid inclusions, has been precipitated, and a further clear quartz zone, also free of fluid inclusions, has been precipitated. The latter crystals terminate into vugs.
hematite:- (2%) occurs as a distinct zone as described above.
Fe-oxides:- (2%) after hematite.
pyrrhotite:- (tr) within a fracture within fluid inclusion quartz as above.
chalcopyrite:- (tr) within a fracture within fluid inclusion quartz as above.
chalcocite:- (tr) within a fracture within fluid inclusion quartz as above.

Interpretation:-
1. Quartz - f.i. rich.
2. Fracturing.
3. Po, ccp, chalcocite.
4. Fracturing.
5. Hm ----> Quartz ----> Jasper ----> Quartz.

Name:- epithermal quartz

JG002 (1-2)
Tollis Formation - Jungle
Ref Nos: A30
DPTS

Macroscopic:- quartz replacement of a possible calcite epithermal rock which has been filled in with Fe-oxide or possibly sulphides of some later phase.

Microscopic:- mostly quartz, goethite and hematite.
quartz:- dog tooth quartz growing parallel to some plane. Initial growth is full of tiny inclusions which are too fine for fluid inclusion work. Clearly the quartz has grown on a plate-like substrate into open space cavities or in replacement of some soft material. A second quartz type, which forms star shaped growth patterns, forms the base on which the plate-like type quartz is situated.
goethite/hematite:- these are clearly later than the quartz as they occur as infill between the quartz, thus suggesting either replacement of the substrate by the goethite/hematite, or goethite/hematite infill of cavities which once contained the substrate.

Interpretation:- the star shaped quartz probably replaces epithermal calcite or has grown of its own accord. The prismatic quartz probably grew on plates of epithermal calcite. The calcite was later degraded leaving an aggregate of brittle quartz prisms. The aggregate was later filled in by hematite which has largely altered to goethite. (===> epithermal activity).

Implications:- epithermal activity has been a feature of the Mount Todd region. Given that some of these textures contain gold, it is likely that gold remobilisation has occurred at some stage in the metallogeny of the Mount Todd region.

Name:- prismatic quartz replacement of epithermal calcite.

JG003
Tollis Formation - Jungle
Ref Nos: A31
TS

Macroscopic:- fine grained siltstone.

Microscopic:- predominantly quartz clasts and poly quartz clasts in a Fe-oxide/sericite matrix; bedding is defined on the basis of clasts size and grain length orientation (not so if rotated by some unseen fabric development);

Clast types (60%) include:-

quartz - angular and contain numerous apatite inclusions,

poly quartz clasts - mostly granoblastic type quartz,

zircons (tr) - subhedral to euhedral,

chert - clasts are angular,

K-spar - slightly sericitised and has very angular margins,

plagioclase - evidenced by multiple twins, also slightly sericitised.

sericite - there exists patches of sericite which appear as psuedomorphs of feldspars.

No clasts exceed 0.2 mm in size.
Matrix (40%) is mostly sericite/Fe-oxide

Interpretation:- This was probably a fine grained siltstone. Given the nature, type and shape of the clasts, it is likely that the parent material was a combination of felsic tuff and marine sediment. There is no definite fabric developed throughout, however, the sericite is probably aligned to produce a weak fabric and is possibly consequent of retrogression after metamorphism.

Name:- Tuffaceous siltstone.

LSS001
Lewin Springs Syenite
Ref Nos: A49
PTS

Macroscopic:- K-spar porphyritic syenite.

Microscopic:-
S-spar:- (25%) multiple and carlsbad twinning types, 2 X 1 mm (200 x 100 μm), heavily sericitised, occurs as individual euhedral poiklioblasts within K-spar or as euhedral to anhedral, heavily sericitised crystals. S-spar also occurs in the groundmass as euhedral to anhedral grains up to 150 μm in size.
K-spar:- (40%) anhedral crystals displaying occasional carlsbad twinning, up to 1 cm in size, margins of the crystals are rounded and enclosed by a dusty sericite rim which is surrounded by a rim of clear K-spar that is in optical continuity with the parent crystal. The texture wold suggest that the K-spars have been partially consumed and may even by xenocrysts rather than phenocrysts. K-spar also occurs in the groundmass as euhedral to anhedral grains up to 150 μm in size.
biotite:- (13%) size ranges up to 400 μm; types range from opaque rich, euhedral biotite to opaque poor chloritised euhedral biotite.
zircons:- (2%) euhedral to subhedral crystals that range up to 300 μm in size but which are, on average, 60 μm in size.
opaques:- (3%) size ranges up to 200 μm; generally anhedral; strongly associated with some biotite although some free grains occur throughout.
quartz:- (15%) occurs in the groundmass as euhedral to anhedral grains up to 150 μm in size.
apatite:- (2%) 100 μm elongate grains throughout the groundmass.

Interpretation:- the quartz, plagioclase and K-spar percentages place this in the quartz syenite field of the Streckeisen diagram. K-spars may be xenocrysts rather than phenocrysts.

Name:- quartz syenite - Lewin Springs Syenite.

MT001b
Tollis Formation - Mount Todd
Ref Nos: A55
PS

Macroscopic:- quartz vein and some mineral.

Microscopic:-
wolframite:- (Fe, Mn) WO_4; masses of interpenetrating laths and acicular crystals; hardness 6-6.5; gray reflectance; deep red internal reflectance. Hematite and goethite coat the mineral and quartz has a higher relief than it. The texture is one that suggests it was crushed and rexlised into fan shaped acicular crystals.
quartz:- masses of quartz crystals.

Interpretation:-
1. Buck quartz vein.
2. Fracturing - wolframite?
3. Fracturing - rexlisation of wolframite in open spaces.
4. Hematite precipitation as fill.
5. Goethitisation.

Name:- quartz-wolframite vein.

MT013
Siltstone - Mount Todd
Ref Nos:- B148
PTS

Macroscopic:- crosscutting veins in siltstone.

Microscopic:- wallrock:- tourmaline, biotite, chlorite, sericite, hematite and goethite. Grain size of 25 μm. (==> sandy siltstone). Po, ccp and rutile (from bt) occur in wallrock.
veins:- vein 1:- quartz-tourmaline. Quartz is polygonal, growth is syntaxial, and there is no evidence of crack-seal growth. Tourmaline occurs as massive tourmaline, bundles and fine grains crystals up to 200 μm long. Vein is crosscut by rare trails of Type B fluid inclusions.
vein 2:- quartz-tourmaline which crosscuts vein 1. Tourmaline is generally orientated perpendicular to sub-perpendicular to the vein wall.
vein 3:- crack-seal quartz which crosscuts vein 1. Quartz crystal terminations are vuggy and hematite dots these terminations.

Name:- quartz-tourmaline veins, crack-seal quartz vein, sandy siltstone.

MTW001
Tertiary nodular clay - Mount Todd West
Ref Nos: A54
TS

Macroscopic:- nodular sandy clay

Microscopic:- About 40% of this poorly sorted sample is pore space. Most clasts are angular to subangular which do not exceed 400 μm in size, i.e., fine to medium sand size. Clasts (25% of the total rock) include quartz (numerous fluid inclusions suggest the quartz is largely sourced from quartz veins), chert fragments, iron oxides, quartzites.
The matrix (35%) is composed of a fine grained quartz (50 to 100 μm), chlorite, sericite, fine clays and Fe-oxides. The 15% proportion of the Fe-oxides gives the unit a distinctive orange colour, and often occurs as a limonite crust which coats pore spaces.

Name:- porous nodular clayey ferruginous sand.

PGD007d
DDH PGD007, 96.12-96.18 m
Ref Nos: A86
DPTS

Macroscopic:- quartz-sphalerite-galena vein

Microscopic:-
sediment:- the section is too thick to determine the composition of the sediment, however, it is brecciated.

vein:- quartz:- occurs as zones around brecciated fragments. Zones are defined by the size of the individual crystals, and by the number of sub-microscopic fluid inclusions. Zones are:-

1. fine grained quartz (< 40 μm). This gives way to coarser quartz crystals (up to 100 μm in size). Fluid inclusion proportions are moderate.
2. zone of quartz crystals in which distinct zones can be recognised.
   a) clear zone (400 μm wide).
   b) fluid inclusion dense zone (200 μm wide).
   c) clear zone (600 μm wide).
   d) fluid inclusion dense zone (40 μm wide).
   e) clear zone (300 μm wide).
   f) fluid inclusion dense zone (200 μm wide).
   g) clear zone (500 μm wide).
   f) vug.

galena:- appears to postdate type 2 quartz zonations and looks as though it forms an infill. Possibly this quartz type was brecciated and galena became fill between breccia fragments.

rutile:- (tr) associated with the sediments and is probably pre-brecciation of the sediment; has a bright white internal reflection.

Interpretation:-
1. Sedimentation.
2. Fracturing.
3. Dog tooth quartz 1 ----> dog tooth quartz 2
4. Fracturing.
5. Galena.

Name:- quartz vein; galena vein in brecciated sediment.

PGD011-4A
DDH PGD011, 60.60-60.75 m
Ref Nos: A166
DPTS

Macroscopic:- brecciated sediment.

Microscopic:-
sediment:- brecciated (section is too thick to make analysis of the sediment type).
vein:- brecciation was followed by the precipitation of zoned dog tooth quartz into open cavities. The zones are defined by fine fluid inclusions (< 2.5 μm). Quartz growth is syntaxial with respect to the wall-rock quartz. The quartz can be divided into two separate zones: a zone closest to the vein wall which is rich in tiny fluid inclusions (qtz 1) and a vein central zone of vuggy clear quartz (qtz 2). Fluid inclusion size is ~3 μm and it may be possible to do fluid inclusion analysis.

galena:- (2%) anhedral masses having curved contact margins with respect to zoned and vuggy quartz, and is probably fill.

sphalerite:- (tr) intimately associated with galena.

Interpretation:- deposition of the sediment, brecciation, quartz precipitation in open spaces (type 1 and 2), fracturing, precipitation of sphalerite and galena.

1. Sedimentation.
2. Fracturing.
3. Dog tooth quartz 1 ----> dog tooth quartz 2.
4. Fracturing.
5. Galena & sphalerite.

Name:- quartz vein; galena vein in a brecciated sediment.

Q001
Tollis Formation - Quigleys
Ref Nos: A21
TS

Macroscopic:- pyritic shale (D. Koerber, pers comm called it an igneous body).

Microscopic:- The section consists mostly of sericite with a strong fabric development. Other minerals present include some carbonate and detrital zircons. The zircons are euhedral to subrounded and 50 μm in size. About 5% of the total section consists of Fe-oxide masses which are very fine (< 0.01 mm in size). Large open cavities may have contained pyrite which has since disintegrated. It is possible to generate a relic bedding from the alignment and close spatial relationship of zircons.

Interpretation:- A heavily weathered, metamorphosed shale. The fine grained nature of the majority of the section, together with the absence of quartz clasts or any clastic material, may support a shale origin for the unit. The presence of detrital zircons would reject the idea that the unit is an igneous body, although to rule out the possibility that the sediment provenance is igneous, would not make sense. Two fabrics are defined by the Fe-oxides and are ~ 60 ° apart. (section is not orientated). The less pervasive, spaced fabric is seen to crosscut the fine pervasive fabric. Some mica-fish are developed.

1. Sedimentation.
2. Deformation - S1 strong, pervasive cleavage.
3. Deformation - S2 weak, spaced cleavage.
4. Alteration.

Name:- a heavily weathered, X2 deformed, shale.

QD001(i)
DDH QD001, 79.2m.
Ref Nos:- B126
PTS

Macroscopic:- quartz-pr-ars vein.

Microscopic:- ars surrounded by py is common and py lies within fractures within ars, suggesting ars predates py.

QD002e (1-2)
DDH QD002, 144.76-144.89 m
Ref Nos: A122
DPTS, PTS

Macroscopic:- Calcite vein

Microscopic:- Sample is of a sediment cut by a vein in which calcite and sulphides have grown.
sediment:- can be described as a poorly sorted, matrix supported, medium, sandstone.
quartz clasts:- angular clasts to 400 μm
chlorite:- matrix material
sericite:- matrix material

sulphide mineralogy:-

chalcopyrite:- (tr) anhedral crystals; 200 μm in size; surrounded by crystalline calcite and therefore is pre-calcite; as a surrounding rim to some galena.

galena:- (5%) euhedral to subhedral crystals

sphalerite:- (tr) anhedral masses of yellow to dark brown colour; often show zonation; occurs in fractures together with dog tooth quartz and some sphalerite inclusions occur in the quartz.

The relationship between sphalerite and galena is not clear because the contact margins, which are smooth and curved, are implicit of either equilibrium or co-precipitation.

The relationship of chalcopyrite to galena is not clear given that chalcopyrite rims galena and fills fractures.

veins:- the sandstone is crosscut by quartz veins which are ~ 1 mm wide. The quartz crystals have initially grown syntaxial to the wall-rock quartz, later becoming dogs tooth type that commonly exhibit a zonation. The veining and morphology of the quartz is implicit of brecciation of the rock and open space quartz precipitation. After quartz, mineral precipitation was; calcite (cal 1, fluid inclusions are numerous but decrepitated), galena (probably synchronous with the sphalerite), and finally several events of calcite.

Cal 2: clear calcite with few fluid inclusions.

Cal 3: very dense with fluid inclusions and may be dolomite, is associated with rays of an unknown mineral (unk 1). The unknown mineral is coloured, slightly pleochroic, strongly anisotropic; has a pearly white internal reflectivity. Its association with cal 3 can be seen in fractures crosscutting the sediment and in fractures in the galena.

Subtle fractures parallel the regional S2 cleavage and crosscut the calcite.

Interpretation:-

1. Sedimentation.
2. Fracturing.
3. Sphalerite ----> quartz ----> galena
4. Fracturing.
5. Calcite 1 ----> quartz ----> calcite 2 ----> cal 3, unknown mineral.
6. S2 fabric.

The timing of the chalcopyrite is not clear.

brecciation => qtz => cal 1 => qtz => cal 2 => cal 3/unk 1. Ccp?.

Name:- calcite-base metal vein in a brecciated, poorly sorted sandstone.

QD002h

Quigleys, DDH QD002, 231.52-231.6m.

Ref Nos:- A125

PTS

Macroscopic:- Po in breccia.

Microscopic:- löellingite:- anhedral grains consumed by arsenopyrite. Probe results indicate Co and Ni decrease with increasing Fe and Ni increases with decreasing S content. S contents are 0.4 - 4.4%. Ni contents are 0.5 to 5.2%.

arsenopyrite:- anhedral to subhedral grains which consumes löellingite. FeAsS plots are depleted with respect to S and As from ideal arsenopyrite.

gold:- associated with bismuth in fractures in arsenopyrite/löellingite grains. Gold fineness = 828.

bismuth:- associated with gold.

T001
Tollis Formation - Tollis
Ref Nos: A7
TS

Macroscopic:- felsic tuffaceous sediment (D. England has called this an airfall tuff which landed on the sea).

Microscopic:- Primary bedding features are clearly evident from hand specimen and thus, the unit must be sedimentary in origin. Generally, the sample is composed of fine clastic material (5 μm). The angular to subangular quartz clasts of 0.4 mm size, but these make up only about 5% of the total sample. These may be quartz shards. Some fragments are lithic.
The matrix of the sample makes up about 95% of the total rock and consists predominantly of quartz, sericite and an opaque which may be graphite. Spotting is evident and must postdate sedimentation since zircons and quartz clasts are incorporated in the spots randomly. The sample is hornfelsed. No preferred orientation of platey minerals.

Interpretation:- It is difficult to say what this is from a macroscopic point of view. There is no doubt that it was a sediment which was deposited rapidly in a reduced environment. It may be a very fine clay although it is difficult to imagine a clay with such a large amount of quartz. The angularity of the grains may suggest it is a felsic tuff and perhaps the alternation between paler quartz rich bands and darker carbon? rich bands would fit better with this conclusion. It is rather difficult to imagine that this is a graphitic shale given that graphite is restricted to specific bands.

1. Sedimentation.
2. Hornfels - spotting.

Name:- graphitic chert.

T002
Tollis Formation - Tollis
Ref Nos: A9
TS

Macroscopic:- greywacke

Microscopic:-
quartz:- (65%) 0.2 mm in size on average; grains are angular to subrounded.
composite quartz grains:- (15%) 0.2 mm in size on average; grains are angular to subrounded.
sericite:- (10%) fine grained (<10 μm) blades mainly as matrix material. Alignment denotes two fabrics which can be seen to partially wrap around clasts: one moderate, one weak cross cutting.
opaques:- (10%) fine (<10-50 μm) masses of iron oxide throughout the slide. Also located along the fabric giving a good indication to fabric orientation.
zircons:-(tr) < 80 μm, subrounded to rounded shape with high relief and birefringence.

Interpretation:- it has not been possible to determine the orientation of the original bedding from clast alignment or from evidence of primary structures. The average clast size is medium using the Udden-Wentworth grain scale (p 325, Ehlers and Blatt). The sediment is poorly sorted and can be termed a silty sandstone.

1. Sedimentation.
2. Deformation with retrogression - S1 moderate fabric.
3. Deformation with retrogression - S1 weak fabric.

Name:- X2 deformed, silty lithic sandstone.

TD002a
DDH TD002, 210.35 - 210.40m.
Ref Nos: A47
PS

Macroscopic:- pyrite-arsenopyrite quartz vein.

Microscopic:-
pyrite:- (50%) subhedral, sub-equant crystals, 100-150 μm in size,margins of the grains tend to be rounded and rimmed with fine ragged pyrite which gives the margins a fluffy appearance, macroscopically, the pyrite is spongy and vuggy, and because it is subhedral, the morphology is suggestive of pyrite replacement of some other mineral.
arsenopyrite:- (15%) subhedral to euhedral crystals, 100 μm in size: occur as isolated crystals or as clumps within the pyrite crystal network. The relationship between pyrite and arsenopyrite is suggestive of syn- to post-emplacement of pyrite with respect to arsenopyrite, i.e., contact margins are straight and the general appearance is of islands of arsenopyrite in a sea of pyrite crystals.
chalcopyrite:- (1%) anhedral masses within quartz, < 125 μm in size, masses up to 1 mm in size.
pyrrhotite:- (tr) euhedral crystals associated with anhedral chalcopyrite, 400 μm in size. The relationship of pyrrhotite to chalcopyrite is suggestive of pyrrhotite precipitation prior to that of chalcopyrite.
sphalerite:- (tr) anhedral masses associated with anhedral chalcopyrite, contact margins are smooth and curved which may indicate co-precipitation or equilibrium - the one not implying the other. The sphalerite contains tiny chalcopyrite inclusions (< 2.5 μm).
covellite:- (tr) supergene alteration produce of chalcopyrite.
quartz:- (35%) major gangue mineral.

Interpretation:- a quartz vein containing sulphides of pyrite, arsenopyrite, chalcopyrite, pyrrhotite, sphalerite, and covellite. Pyrite may replace another mineral or be a syn- to post-precipitate of arsenopyrite. Pyrrhotite preceded chalcopyrite, the chalcopyrite may be coeval with sphalerite. Covellite is a supergene product.

i.e., ars => py => po => ccp/sp => co.
ars/py => po => ccp/sp => co.
ars => py => po => ccp => sp => co.
ars/py => po => ccp => sp => co.

Name:- pyrite-arsenopyrite-quartz vein.

TD002b
DDH TD002, 220.47-220.51 m
Ref Nos: A48
DPTS

Macroscopic:- quartz

Microscopic:-
quartz:- (99%) an aggregate of zoned dogs tooth quartz crystals. Zones are defined by fluid inclusions which are generally < 2.5 μm in size. Can be used for a fluid inclusion study. The section clearly has vugs, vuggy dogs tooth crystalline masses are implicit of open space fill. The nature of the fluid inclusions would suggest a low temperature of formation and it is likely the sample represents epithermal precipitation of quartz. The array of dogs tooth quartz is such that a fine (< 1 μm) mass of quartz crystals forms a substrate on which zoned dogs tooth quartz has grown. This is similar to that described elsewhere for epithermal growth of dogs tooth quartz (JG002).
sphalerite:- (1%) anhedral masses, very brown to yellow in colour in transmitted light, generally as fill to fractures.

Interpretation:- epithermal zoned dogs tooth quartz has grown on some substrate which was itself replaced by quartz. A fracturing event was followed by the precipitation of sphalerite and clear fluid inclusion free quartz. The zoned quartz and the sphalerite contain fluid inclusions which may be useful for study.
i.e. possibly calcite blades => growth of dogs tooth quartz perpendicular to blades + replacement of the calcite blades => fracturing => precipitation of sphalerite and fluid inclusion clear quartz into open spaces. Some vugs still remain.

1. Host mineral.
2. Dog tooth quartz & replacement quartz.
3. Fracturing.
4. Sphalerite and quartz.

Name:- epithermal quartz.

TD002f
DDH TD002, 221.09-221.135m.
Ref Nos:- A135.
PTS

Macroscopic:- po vein, quartz vein.

Microscopic:- po in loell in gn.
po in loell in sph.
po>ccp>py in gn and sph.
gn in sph.
py in marc in gn.

VV001
Burrell Creek Formation- Vicky Vale
Ref Nos: A24
TS

Macroscopic:- arkosic grit to conglomerate.

Microscopic:-
Clasts:- (60%), are matrix supported.
(a) igneous: clasts containing sericite plates after feldspar. Feldspar clasts are mostly sericitised and hematised. Clasts of glass contain rays of some quenched mineral which has totally been altered to sericite.
(b) sedimentary: clasts of shale, quartzite, chert, and rock fragments.
(c) quartz clasts: generally angular and go to complete extinction (therefore no strain post deposition)
Generally clasts do not exceed 3 mm in size and are rounded to angular.
Matrix:- (40%): consists of an interlocking network of fine grained angular quartz, quartzite, rock fragments and sericite. Fe-oxide masses are general throughout and detrital zircons are common. Some chlorite is also present.
If clast length orientation is examined, a weak bedding may be determined. Perpendicular to this direction, are short Fe-oxide fractures (0.5 - 1.0 mm) which cut clast edges, cut across the matrix, or hug clast margins. The fractures are generally orientated in the same direction and are suggestive of extension. Perhaps the fractures define a weak fracture cleavage. There is certainly a weak fabric developed, as determined from the alignment of sericite in shale clasts and to a limited extend, in the matrix. The approximate angle between fabric and the Fe-oxide fractures is 60°-30°.

Interpretation:- a metamorphosed, moderately sorted, granular gravel. The section suggests two deformational events have occurred: one forming a cleavage as demonstrated by the alignment of platey grains, the other forming a weak fracture cleavage as defined by parallel Fe-oxide fractures.

1. Sedimentation.
2. Deformation - S1 fabric.
3. Deformation - S2 spaced fracture fabric.

Name:- X2 deformed, granular meta-gravel.

WB001
West Batman
Ref Nos:- B149
TS

Macroscopic:- Hornfelsed igneous rock .

Microscopic:-
Area 1:- spotted in form. Occasional clasts of quartz (100 μm) in a matrix of quartz (25 μm), sericite, biotite (10 μm) and zircons. (=> hornfelsed siltstone) The spots consist of anhedral chlorite (one lath generally - 600 μm) which contain "chadacrysts" of anhedral quartz (50-70 μm), rutile needles in bundles (10 X 25 μm), equant anhedral K-spar (100 μm), and anhedral muscovite laths. The spots are commonly surrounded by a zone of anhedral quartz and K-spar, then muscovite laths, then quartz, and finally quartz and sericite.
Area 2:- anhedral clasts of quartz to 100 μm, in a matrix of quartz (25 μm), sericite, chlorite and zircons. (N.B. many more quartz clasts than for area 1, i.e., => hornfelsed sandy siltstone)
A fabric is clearly evident throughout the rock and is defined by an elongation of the spots and by sericite and chlorite alignment.
veins:-
vein 1 - In Area 3, vein 1 consists of quartz, chlorite, K-spar and bundles of rutile needles, while in Area 2 the vein consists of K-spar. In Area 1 adjacent to Area 2, the vein consists of chlorite/sericite/muscovite and bundles of rutile needles, while away from Area 2 it consists of quartz, chlorite, K-spar and rutile needles. All crysts are coarse grained.
vein 2:- consists of quartz, k-spar and muscovite/sericite. This is probably a vein in whichK-rich fluids seem to have moved through the rock and altered all except the quartz.
vein 3:- consists of recrystallised quartz surrounded by an alteration zone of sericite and quartz.

Interpretation:-
1. Sedimentation.
2. Hornfelsing and spotting. ?Cordierite.
3. Deformation - S1 fabric.
4. Hornfelsing and biotite development.
5. Veins of quartz, chlorite, muscovite, and rutile.
6. K-metasomatism and the re-equilibration of muscovite to K-spar together with the general emplacement of K-spar. The spar is most likely adularia.

The unit in the field is only 0.75 m thick and is very highly altered in comparison to the adjacent units. It seems that this particular strata favoured K-metasomatism and may well have been a primary channel for metasomatic fluids.

Name:- X2 hornfelsed, K-metasomatised siltstone and sandy siltstone, quartz-chlorite-K-spar-rutile vein, quartz vein.

WB002
West Batman
Ref Nos:- B149
TS

Macroscopic:-orientated sample of slickenslides from the hornfelsed zone. The slickenslides are orientated 37° -> 284° and movement in the field was determined to be bedding parallel reverse dislocation.

Microscopic:-
wallrock:- biotite:- (40%), euhedral crysts to 10 μm in size.
quartz:- (40%), anhedral equant grains to 10 μm.
sericite:- euhedral crysts to 10 μm in size. In the wallrock, it forms 20% of the matrix. However, spotting is evident throughout and within the spots the proportion of sericite increase to 40 %, while that of biotite decrease to 20 %. The sericite defines a fabric, especially in the spots. The spots (up to 250 μm in diameter) are elongate parallel to the fabric.

Problem:- 1. Biotite and cordierite may have formed during hornfelsing which is syn-deformational thus resulting in ovoid cordierite clots which quickly retrogressed to sericite and chlorite, leaving the biotite behind.
2. Biotite and cordierite = hornfelsing 1 - Yenberrie leucogranite; Deformation (D1); biotite and cordierite - Tennysons leucogranite; Deformation (D2); ? biotite recrystallisation.

slickenslides:- layers of quartz show clear indication, both macroscopically and microscopically for reverse faulting during flexural slip, i.e., $\sigma 1$ was orientated ~ E-W. This is indicated from quartz fibre root ties, stepping of the bed surface, and the presence of micro veins dipping ~ to the east. N.B. The fibres consist of large quartz elongate laths with considerable polygonal to sub-polygonal subgrain development, and euhedral biotite and muscovite to 350 μm.
vein:- vein 1:- these are associated with the slickenslides and extend down from near to the base of the slickenslides into the sediment, and then die out some 1.5 cm from the base of the slickenslides. The fabric cutting through the clots also cuts through these veins. The veins consist of quartz and biotite.
vein 2:- crack-seal quartz. Quartz crystals extend across the vein width.
N.B. Biotite is found in a particular layer of the slickenslides, within slickenslide veins, within the wallrock and most of the clots. The fabric is found within clots, wallrock and slickenslide veins.

Interpretation:-
1. Sedimentation.
2. Hornfelsing and the development of cordierite spots. ?Biotite.
3. Retrogression.
4. Deformation and the development of a fabric. Bedding parallel flexural slip.
5. Hornfelsing and the development of biotite, recrystallisation of the slickenslides.
6. Quartz.

Name:- D1 slickenslide, X2 hornfelsed siltstone, crack-seal veining.

WB003
West Batman
Ref Nos:- B150
TS

Macroscopic:- spider veins in hornfels.

Microscopic:-
wallrock:- Matrix supported angular quartz clasts and occasional lithic fragments to 150 µm.
matrix:-

quartz:- anhedral fragments to 10 µm.
biotite:- subhedral laths, 5 X 10 µm in size.
opaques:- 5 µm blebs.
The matrix is spotted (individual spots are 200 µm in diameter). The spots are composed of chlorite, sericite and quartz. The spots do not contain biotite. Two fabrics are evident throughout the matrix especially within spots. They lie at 61° to each other.
(=> hornfelsed, fine grained lithic sandy siltstone).

veins:-

vein 1:- quartz-chlorite-opaques-muscovite. Where the muscovite and the chlorite abut, rutile needles are commonly present. It looks like the muscovite is forming after, and consuming the chlorite, but it is not altogether clear. The chlorite, quartz, muscovite and the opaques are all post wall rock. The opaques are hematite and rutile.
vein 2:- goethite vein:- crosscuts vein 1.

Interpretation:- The spider veins are quartz-chlorite-opaque veins. Muscovite lies central to the vein as does the larger laths of chlorite (CHLORITE ANALYSIS). Quartz, chlorite and the opaques are throughout the alteration halo. Both vein types crosscut the spotting, the fabric and the biotite wallrock material.
Two hornfelsing events are herein argued: the development of cordierite spots, development of biotite. Cordierite is favoured as the first event since it is the higher temperature mineral. WHY?

(i) If the biotite was first it would have been consumed in the higher temperature reaction needed for cordierite.
(ii) Some biotite is found in the spots themselves and thus must postdate there development.

1. Sedimentation.
2. Hornfelsing - cordierite spotting.
3. Deformation retrogression - S1 fabric.
4. Hornfelsing - biotite development.
5. Quartz-chlorite-opaque vein => muscovite.
6. Goethite veining.

Name:- X2 hornfelsed, fine grained lithic sandy siltstone; quartz-chlorite-muscovite-opaque vein; goethite.

Y001
Tollis Formation - Yuckville
Ref Nos: A52
TS

Macroscopic:- folded shale.

Microscopic:- Is composed of quartz, chlorite and Fe-oxides, and no crystals exceed ≈ 25 μm in size. Chlorite and sericite define a cleavage and Fe-oxides define cavities, crosscutting and cleavage parallel fractures, and cleavage. Bedding is defined by the difference in the proportions of the above minerals. Some beds contain a preponderance of Fe-oxides and cavities lined with Fe-oxide. The cavities probably contained pyrite which has long since been weathered.

Cleavage is axial planar and well developed.

Relic cordierite spots exist but these have been completely altered to chlorite and sericite. The spots are pre-cleavage in age, simply because the axial planar cleavage traverses the core of the spots and because the spots are elongate in the direction of the cleavage. Spot diameter ranges up to 400 μm in size. Cordierite spotting indicates that hornblende-hornfels facies metamorphic conditions (H1) has been achieved prior to the development of cleavage.

A second set of cordierite spots (H2) (up to 100 μm in size) are post cleavage in that they do not appear to be traversed by the above mentioned cleavage, nor are they elongate. They are altered to very fine sericite and chlorite (< 5 μm), the size of the laths being considerably finer than that of the matrix.

The two types of cordierite spots would support a pre-fabric hornfelsing event, and a post-fabric hornfelsing event, as mentioned elsewhere. The sample is veined by small spider-like quartz veins (< 0.5 mm width) which are predominantly sub-parallel to cleavage (30° - 40° to cleavage). The veins show some crack-seal quartz development and were probably formed at the same time during some deformational event. The veins cross-cut and occasional offset, both cordierite spots types. If the veins formed during a deformational event then that deformation must have post-dated both hornfelsing events.

Interpretation:- a doubly hornfelsed, folded shale which has been chloritised and sericitised, and fractured.

1. Sedimentation.
2. Hornfels 1 - spots after cordierite.
3. Deformation with retrogression - S1 fabric.
4. Hornfels 1 - spots after cordierite. Also biotite.
5. Crack-seal quartz.

Name:- X2 hornfelsed pyritic shale with a X1 fold history.

YEN001
Yenberrie leucogranite
Ref Nos:- None
TS

Macroscopic:- two mica leucogranite

Microscopic:-
biotite:- (10%), green brown subhedral laths to 2 mm in size. Associated with Ur haloes and thus zircons. Some chloritisation.
S-spar:- (10%), subhedral laths to 400 µm. Ab34An = Andesine. Some sericitisation.
K-spar:- (40%), subhedral laths to 2 mm in size. Patchy microcline twinning. Patchiness associated with the beginnings of a fabric. Some sericitisation and deuteric alteration.
muscovite:- (5%), as alteration of feldspars and biotite, and as rare euhedra. Tends to be secondary.
quartz:- (35%), generally throughout as clear crysts. Margins display some concavo-convex texture. Weak wavy extinction.
zircons:- accessory - in biotite.
A weak fabric can be detected in the form of parallel fractures throughout the section, from the alignment of muscovite laths, wavy extinction in quartz, and from the patchy nature of feldspar.

Interpretation:-
1. Emplacement of leucogranite.
2. Greisenation.
3. Deformation - (*?)

Name:- greisenated and weakly deformed coarse grained biotite-andesine-microclino-quartz leucogranite.

YEN020A
Yenberrie leucogranite
Ref Nos:- None
TS

Macroscopic:- two mica leucogranite.

Microscopic:-
biotite:- (20%), euhedral laths to 3 mm. Pale brown to greenish in colour and slightly chloritised (colour mainly caused by Fe^{2+} and low Fe^{3+} and Ti).
zircons: (tr), anhedral crysts to 30 µm in size. Associated with Ur haloes.
quartz:- (45%0 subhedral to anhedral crysts to 1.5 mm. Numerous secondary fluid inclusions transect the crysts and together with slight wavy extinction, indicate that some stress has been applied to the rock.
muscovite:- (15%), euhedral laths to 3 mm. Pleochroic in pinks and pale yellow. Some replacement of biotite.

Quartz-filled stress fractures are evident in part, fine secondary inclusion trails, wavy extinction in quartz, subgrain development and concavo-convex boundaries to all crysts suggest that the rock has been stressed. Field examples indicate that the granite has been slightly deformed during D1.

Interpretation:-
1. Emplacement of the leucogranite.
2. Greisenation.
3. Deformation - (*?)

Name:- greisenated and weakly deformed, coarse grained biotite-quartz leucogranite.